PRINCIPLES OF X RAY AND RADIUM DOSAGE

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of
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by

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PREFACE

Roentgen ray and radium therapy has passed over a long and rocky road. The first enthusiasm inspired by the results of surface therapy was succeeded in 1905 by a realization of the many harmful effects of the rays. As a consequence radiation therapy entered a period of depression from which it slowly emerged with the prevention of injury as its goal. Dosimeters were introduced, which enabled a determination of the intensity and of the quality of the rays and made a sure dosation possible. Innumerable single treatments led to treatment methods, which were more or less certain of success and avoided serious injuries.

Deep therapy passed through similar stages. The use of very penetrating rays for the treatment of diseases which have their seat within the body produced results far beyond expectations. However, serious injuries soon appeared. At present therefore the general conviction is that caution must be observed; that existing methods must be subjected to thorough test and revision; and that formulæ and methods must be developed, which increase the surety of the treatment. In the broadest sense we are dealing with the question of correct dosage. But both the problem of correct dosage as well as the correct application of the dose are much more difficult here than in the case of surface therapy. Not only difficult measurements but difficult calculations must be made. To carry out a cross fire irradiation the entire treatment must be carefully planned in advance. For this a knowledge of the physical and of the biological action of hard

rays is necessary; moreover, a knowledge of the methods of measuring, calculating and applying the radiation is required. The present volume is to contribute to this end; it treats of the most recent methods of practical dosage.

It is assumed, that the reader is already familiar with the elementary principles of physics and of measuring technique; a discussion of fundamental concepts such as voltage and amperage, description of transformer and tube, as well as a discussion of the fundamental phenomena of radioactivity, has therefore been omitted.

These subjects are so well known and have been so frequently and thoroughly discussed, that we shall merely give a few references.

For the fundamental physical concepts we recommend the text books of physics in use at various high schools and colleges. For a discussion of electrical apparatus and phenomena within the tube we recommend the article by John K. Robertson in the Radiological Journal, 1923: "X-Rays and X-Ray Apparatus." For a study of radioactivity, N. E. Dorsey's excellent book: "The Physics of Radioactivity" may be recommended.

This volume deals chiefly with the following subjects:

Chapters I and II treat of the exact definition and methods of measurement of both intensity and hardness.

In Chapter III the distribution of the Roentgen and radium radiation in the tissues are discussed on the basis of the most recent physical investigations.

In Chapter IV the problems of relative and absolute dosage are thoroughly discussed in the light of the latest developments.

In Chapter V, finally, the most important doses likely to occur in practice are illustrated by a series of cases and

treated from the standpoint of the most recent advances in deep therapy.

It has been the author's aim throughout the book to enable and encourage the reader to do his own thinking so that he can stand squarely on his own feet. Only in this way it is possible to discourage the strong tendency toward routine methods of treatment.

In the opinion of the author one disadvantage of the available literature, especially of text books, is the fact that only radium therapy or only Roentgen therapy is treated; the two fields are never clearly differentiated, nor is the field where the two overlap, namely, combined Roentgen-Radium therapy, adequately covered. In the present volume particular attention has been paid to these points.

If, however, Roentgen therapy has been given more space than radium therapy, it has been done for two reasons; first, because the calculation and application of Roentgen radiation is fraught with much greater difficulties than that of radium radiation; and second, because radium rays can be considered as special cases of Roentgen rays and cathode rays and can therefore be conveniently discussed with them. Furthermore, there is no occasion for again discussing a subject which has already been adequately treated in Dorsey's excellent book: "The Physics of Radioactivity."

Besides drawing on his own experience and investigations the author has gleaned a great deal of material from the literature—the German literature in particular since it was particularly easy for him and not so readily available to the reader as the Anglo-American literature.

In the form of tables and curves the book contains a wealth of material useful in practice. Unfortunately,

the isodosage charts could not be inserted in natural size. However, such charts can be obtained directly from the author. (See page 1.)

The study of this volume shows that the character of X-Rays is as well known today as the character of light rays and Hertzien waves. The unknown quantity x is no longer present. Twenty-seven years ago their discoverer was justified in modestly calling them X-Rays; today we have reason for calling them Roentgen rays out of recognition and thankfulness to him. For this reason the author has given the latter term the preference.

The author wishes to express his thanks to Mr. Alfred W. Simon for his translation of the manuscript into English and also to Dr. R. A. Ziehn for his assistance in the preparation of the biological portions of this work.

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INTRODUCTION

The Production of Radium and Roentgen rays.

The most important of the known radioactive elements are radium and mesothorium.

Radium, an alkali earth element, similar to barium, of atomic weight 226, is used chiefly in the form of its compounds as chloride, bromide (soluble), sulphate and carbonate (insoluble). In decomposing it emits three types of radiation: alpha, beta and gamma rays.

The alpha rays are positively charged helium nuclei thrown off by the disintegrating radium atoms. These nuclei have a relatively large mass, hence acquire a lower velocity and are less penetrating than the beta rays.

The beta rays are negatively charged particles (electrons), which are projected with enormous velocities.

The gamma rays are a wave motion in the ether very similar to light and Roentgen radiation and differ from these two only in wave length. The shortest known wave lengths and most penetrating rays occur among the hard gamma rays.

Radium is produced in the course of time from uranium and the two are found in nature in definite proportions. To each gram of uranium there corresponds 0.333 micrograms of radium, that is 1/3 of a millionth of a gram. Radium decomposes so slowly that it requires some 1690 years for a given quantity to decay to one-half that quantity. This period is accordingly called the half decay period. The average life, that is the average value of the actual life of all radium atoms, amounts to 2440 years.

The transformation products of radium are two gases, inactive helium and active radium emanation. The atomic weight of the latter is 222. Both radium and radium emanation send out only alpha rays, it is only the further products Radium A and Radium B, etc., which send out beta and gamma rays. The half decay of radium emanation is less than 4 days, 3.81 days to be exact, hence it disappears very rapidly if it is separated from the parent substance. If the emanation remains in contact with the parent substance as in a closed container, then a state of equilibrium is reached in about 30 days. It is only when this stage of equilibrium is attained that radium has the full alpha, beta and gamma activity. If the emanation is continually removed, the intensity of the radiation is reduced to a small fraction of its value at equilibrium.

Mesothorium is a decomposition product of thorium, and decomposes with the production of beta and gamma rays into products which sent out alpha, beta and gamma rays. The half decay period of mesothorium is 6.7 years; its products also are short lived. Since the radiations of radium and mesothorium are not markedly different, there is a possibility that a buyer may receive active preparations of mesothorium instead of the longer lived and more valuable radium. This will not be the case, however, if the radium is purchased from the leading radium companies who issue a certificate guaranteeing that the preparation contains only radium and not mesothorium.

Radium and its salts are measured in grams, milligrams, and micrograms of the element. The emanation is measured in curies, millicuries, and microcuries. One curie of emanation is the amount which is in equilibrium

with one gram of radium; 1×10^{-10} curies is called one eman. To determine the quantity of mesothorium, it is compared with radium; one gram of mesothorium is defined as the quantity which produces the same intensity of radiation as one gram of radium when both are filtered through 5 mm. of lead.

Radium and other radioactive substances are widely distributed in nature. The best known radioactive ores are pitchblende and carnotite. Radioactive materials can be detected in small quantities in all earths and minerals. The igneous rocks (crystalline slate, granite, etc.) contain about 3×10^{-12} grams of radium per gram of rock and 2.6×10^{-5} grams of thorium. In sedimentary rock radioactive elements occur in very different concentrations. The greatest concentration is found in clays; the least in lime and sandstone.

Nearly all springs, especially those which originate in eruptive strata, show a content of radium emanation, at times radium as well. Of the well known therapeutic springs, Oberschlema contains 21000 eman per liter or 2 microcuries per liter.

The Wettinquelle Bad Brambach 8250 eman per liter or 0.8 microcuries per liter.

Quarry water, Joachimstal, 2200 eman per liter or 0.2 microcuries per liter.

Springs, Gastein, 1500-2000 eman per liter.

Springs, Kreuznach and Karlsbad, 100-630 eman per liter.

Springs, Wiesbaden, 80-240 eman per liter.

Most springs and rivers contain traces, 1 to 10 emans. Ocean water is almost totally inactive.

Also the atmosphere contains radium emanation, chiefly near the ground. This is due to two causes. First

the radium emanation comes from the ground and second the emanation is much heavier than air and sinks to the lowest level.

The greatest emanation content is found in caves; the air in the tunnel of the Porphyr Mountain at Kreuznach contains as much as 900 emans per liter.

A very penetrating gamma radiation has been observed in the atmosphere especially at high altitudes. The distribution of this radiation would lead to the conclusion that it is of cosmic origin. This radiation very likely originates from beta particles of high velocity, which are projected by the sun. On account of its radioactive content the air is ionized; the greatest concentration of ions being found near the ground, in caves, as well as at high altitudes.

From this viewpoint the administering of radium in small doses (radium-water, inhalation of emanation) is a very natural cure; it reestablishes conditions, which are excluded by our modern civilization. While primitive man was always in contact with radioactive materials by living in caves, sleeping on the ground, drinking from springs, etc., these things are entirely lacking in the household of civilized man. Very likely radioactive factors are equally as important for the stimulation of metabolism and the prevention of a series of diseases as sunshine and fresh air.

For the production of Roentgen rays a great variety of electrical apparatus and tubes is available.

The voltage between 140 K. V. and 230 K. V. used at present can be delivered by the following apparatus:

(a) Static machines. On account of their low output they can only be used for experimental purposes, not for treatment.

(b) Induction coils. These were used chiefly with gas tubes during the development period of Roentgen technique. In Europe they are still widely used.

(c) Alternating current transformers with rectifiers. These have found the widest application, especially in America. All discussions and measurements in this volume refer to tubes which are operated in this way.

(d) High voltage batteries. For experimental purposes for which a constant potential is required high voltage batteries are particularly suitable. They are used in a few laboratories in the United States.

(e) Apparatus of Hull. An apparatus which is very promising is that devised by Hull and De Coudre; it consists of two thermionic vacuum tube rectifiers together with the proper inductances and capacities for rectifying the alternating current wave and reducing the fluctuations to less than 1 per cent.

The gas tube is gradually disappearing from Roentgen practice.

The present volume is concerned only with radiation produced by Coolidge tubes; all measurements have been made with Coolidge tubes. While in the Coolidge tube the intensity of the radiation is controlled independently of the voltage by varying the temperature of the filament and therefore the number of available electrons, in the Lilienfeld tube used in Europe the filament is always at the same temperature and is large enough to produce an excess of electrons, the number supplied to the anticathode being regulated by an auxiliary circuit.

Recently Lilienfeld has introduced a new tube in which a point electrode is placed only a few millimeters away from the anticathode in an extremely high vacuum. On account of the high potential gradient, electrons are

pulled out of the cathode and projected against the anticathode. These electrons carry the electric current and produce the Roentgen rays. The author is not of the opinion that this type of tube is very promising since the principle of the independent regulation of current and voltage is again abandoned in this design. The tube so far is useful only for diagnostic purposes and not for deep therapy.

CHAPTER I

Determination and Measurement of Quantity

§ 1. Intensity, Energy, Dose.

Two important properties completely define a light ray physically, namely: intensity and color. A statement as to quantity and one as to quality are therefore necessary to characterize a light ray. The same holds for Roentgen rays and radium rays. The corresponding terms here are intensity and hardness.

This chapter deals with the determination and measurement of intensity; the following one will be devoted to the determination and measurement of hardness.

The intensity of radiation is the amount of energy which falls in unit time (1 second) on unit area of a surface (1 square cm.) perpendicular to the direction of propagation of the radiation. Therefore it is the energy density produced or applied during unit time.

This magnitude is of importance technically because it is a direct measure of what might be called by analogy the (candle) power of the Roentgen ray (light) source. The value of a given Roentgen ray installation can thus be easily estimated by the intensity of radiation it emits. Of course, the hardness of the radiation must also be considered before a given machine can be completely characterized.

A knowledge of the intensity of the radiation is further of great practical importance on account of the fact that the biologic reaction depends to a marked degree on the intensity and the time of radiation conjointly. The

product of intensity and time of radiation is called the surface energy. This definition can be expressed by the simple equation:

$$E = I \times t$$

(Surface energy = Intensity × Time)

This equation states that the same surface energy can be applied in various ways: a small intensity can be applied for a long interval, or a large intensity can be applied for a short interval, to produce the same final result. If the product is the same in both cases, the same surface energy has been applied.

The biologic effect, however, depends to a much greater degree on the amount of energy actually absorbed by the tissues than it does on the surface energy applied. It has been found universally true in physical science that only absorbed energy can be transformed into other forms of energy. Instances of this are: the production of heat, secondary electron emission, chemical dissociation, etc. It is therefore reasonable to suppose that only absorbed energy can produce biologic reactions. It will be shown later that the soft rays are absorbed to a much greater degree than the hard rays. Hence the two kinds of rays will appear to produce very different physiological effects if they are compared in terms of surface energy. If, however, they are compared on the basis of absorbed energy, the dependence of the biologic effect on the hardness of the radiation is not so marked.

It has been found that the general reaction of a patient to extensive radiation is governed by the total quantity of energy absorbed, and therefore transformed, in the interior of the body—other factors, such as the region treated, being the same. On the other hand, a local reaction, say of the skin or of cancer tissue, is determined

primarily by the energy density applied. Very different results will be obtained when a small region of the skin is subjected to a high energy density than when a large surface is subjected to the same total energy but to a proportionately smaller energy density. In the latter case the energy absorbed per cubic centimeter governs the biologic reaction. The energy absorbed per cubic centimeter of tissue is called the volume energy or dose.

If the distribution of energy in the interior of a given volume is not uniform, the volume may be thought of as divided into a number of thin strips at every point of which the absorbed energy is practically the same; and these strips may further be thought of as bounded in such a way that each of them encloses one cubic centimeter of tissue. In this way the dose can also be defined for thin surface layers.

To show the application of this idea let us consider the following problem:

Required to determine whether a surface inclined at an acute angle to the direction of propagation of a Roentgen ray beam receives the same or a smaller dose than a surface which is perpendicular to this direction.

Let a beam of Roentgen rays (Figure 1-a) fall perpendicularly on a surface layer and let the thickness of the layer be such that its volume is exactly one cubic centimeter. The dose within a layer depends on the energy which reaches the surface together with the distance over which absorption can occur. The distance in this case is l_1 and is equal to the thickness of the layer.

Consider next the condition represented by Figure 1-b, in which the Roentgen ray beam strikes the surface of the layer obliquely. The same amount of energy is

spread over a larger surface, the energy received per square centimeter is smaller in proportion. However, the path along which absorption takes place is greater in the same proportion (l_2) so that the dose which the layer receives is exactly the same as before. A smaller surface energy but greater absorption produce exactly the same

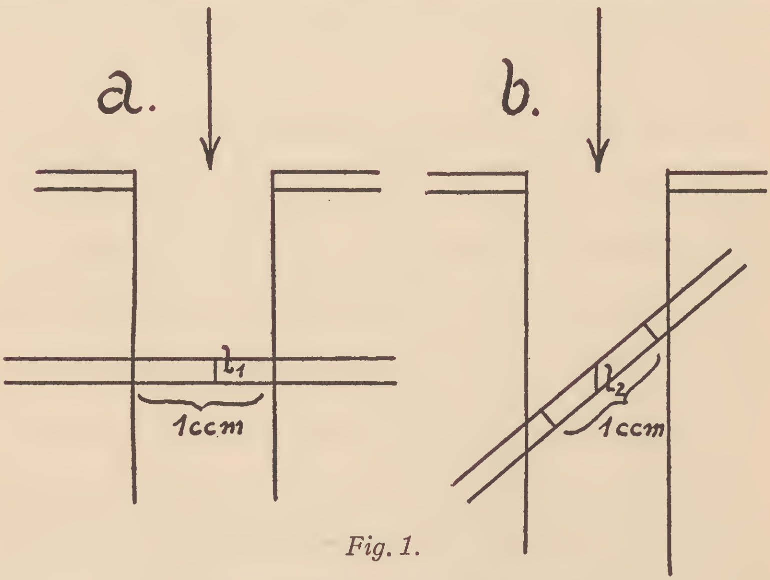

Fig. 1.

Perpendicular and Oblique Irradiation.

dose when the beam strikes the surface layer obliquely as when it strikes perpendicularly. This conclusion is correct only for hard, penetrating rays for which it can be assumed that the energy absorbed at all points of the layer is approximately constant. For very soft rays such as those used in skin therapy the above conclusion does not hold; with these rays the dose decreases as the angle between the path of the rays and the plane of the surface decreases.

It is notable in this connection that several of the

recent books on high voltage therapy give an incorrect formula for the dose produced by an oblique beam. The correctness of the conclusion drawn above may easily be subjected to the test of biological and physical experiments. A film bent into a cylinder is struck at all angles from zero degrees to ninety degrees when exposed to a Roentgen ray beam, but shows uniform optical density[1] on being developed. The position of a film relative to the direction of the beam cannot be deduced by an inspection of its optical density. According to the formula given in several books, the intensity ought to assume all values from a maximum down to zero, the latter occurring in the regions of grazing incidence. When the buttocks are rayed the skin surfaces inclined towards the sagittal plane show an equal or even greater erythema than the surrounding regions; according to this formula they should show a much milder erythema on account of the inclination of their surface to the path of the rays. As a matter of fact, it is found that the scattered radiation comes into play and actually produces a somewhat greater erythema on these surfaces than occurs elsewhere.

In the following we shall take up in detail methods of measuring the intensity and the energy of a beam of rays. Each such method is based on the transformation of absorbed energy and this, in turn, depends on the hardness as well as the intensity of the radiation. For the sake of simplicity the effect of hardness will be ignored in this chapter but any uncertainties introduced in this way will be cleared up in a later chapter.

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[1] Optical density is a measure of the degree of blackening or opacity of the film.

§ 2. Indirect methods of measurement.

The methods, which are used for the estimation or measurement of the energy of Roentgen rays or radium rays, can be classed as direct and indirect methods.

An indirect method measures the primary conditions which govern the production of the radiation and endeavors to deduce the energy from these conditions.

The factors, which determine the energy applied to a point at the surface of the skin are:

1. Kilovoltage.
2. Milliamperage.
3. Transformer and type of rectifier.
4. Roentgen ray tube.
5. Filters.
6. Focal skin distance.
7. Size of field.
8. Time of exposure.

On account of the large number of variable factors an accurate determination of the radiated energy is possible only if most of the factors are held constant. The usual and widespread custom of speaking in terms of milliampere minutes is justifiable only when the other factors enumerated above are kept constant. The statement that 600 milliampere minutes produce an erythema usually assumes the following conditions:

1. 200 kilovolts (peak value).

3 and 4. A commercial transformer, full wave rectification, Coolidge tube.

5. 1 millimeter of copper plus 1 millimeter of aluminum.

6. 50 cm focus skin distance.

7. Approximately $(20\ \text{cm})^2$ size of field.

2 and 8. 600 milliampere minutes, say five milliam-

peres for two hours or six milliamperes for 100 minutes. Should any one of these factors be radically different from the above, the applied energy cannot be deduced from the measured milliampere minutes without some further calculations. In such cases the amount of applied energy can be deduced by the use of certain more or less familiar physical principles. This will be illustrated by the following examples:

Ex. 1. 180 kilovolts instead of 200 kilovolts are used.

The intensity of strongly filtered rays is approximately proportional to the square of the kilovoltage. The calculation is best carried out in terms of percentages, taking into account the fact that if two numbers differ from each other by a small percentage, their squares differ from each other by double this percentage. As an illustration consider the numbers 90 and 100; 90 differs from 100 by 10%. The square of 90, 8100, differs from the square of 100, or 10000, by 19% or roughly, 20%, which is double 10%. Again 105 is 5% greater than 100; its square, 11025 is approximately 10% greater than the square of 100 or 10000. This holds approximately up to plus or minus 20%.

Returning to our problem, 180 kilovolts is 10% less than 200 kilovolts. The intensity of the radiation is therefore diminished; that is to say, with the same number of milliampere minutes 80% of the required energy is applied. Hence 25% more milliampere minutes or 750 milliampere minutes produce the same reaction with 180 kilovolts as 600 milliampeters produce with 200 kilovolts.

Ex. 2. The milliamperage is to be decreased from 5 milliamperes to 4 milliamperes.

As a first approximation, it is necessary to increase the time in the inverse ratio of the milliamperage.

In some cases where the milliamperages are widely different, radical departures from this rule are noted. For every milliamperage there is a best setting of the rectifier. If the correct adjustment has been made for 5 milliamperes then the output at 8 milliamperes will be less than would correspond to the ratio 8 : 5. It may perhaps be nearer in the ratio of 7.5 : 5. Conversely, if the rectifier has been set for maximum efficiency at 8 milliamperes, then the intensity may decrease in the ratio of 4.7 : 8 when the milliamperage is changed from 8 to 5 milliamperes. Two tube operation and single tube operation are sometimes very different since the two tube operation corresponds to double milliamperage. Some installations will work best with two tubes, others with a single tube. When a machine is calibrated, the calibration should be made in terms of the conditions most likely to be used in practice. With some transformers and rectifiers two and three tube operation is inferior to single tube operation so that increasing the number of tubes does not increase the output in proportion to the number of tubes.

Ex. 3. From the output of one installation the output of a second installation is to be deduced. The same operating conditions are assumed.

The wave form of two installations can be so different, that the radiation intensities vary as greatly as from 1 to 6. An installation which maintains constant potential across the tube can produce about three times as much *hard* radiation as an ordinary installation consisting of a good transformer with a mechanical rectifier. When *light* filtration is used, the transformer-rectifier installation does not compare so unfavorably with the constant potential apparatus as regards *intensity*, but in

this case the difference in *hardness* is more pronounced and is in favor of the constant potential apparatus. Two constant potential installations do not differ in output since all factors including the wave forms are the same. However, the various transformers found on the market are very unlike in many respects, due to the various wave forms caused by various constructions in transformers (i. e., magnetic leakage, autocontrol or rheostat control) and peculiar rectifying designs, all of which tend to change the characteristics of the wave form and the phase relationship.

In some installations high voltage surges occur, which in some cases are so strengthened by electrical resonance. These surges can so influence a sphere gap measurement, that an accurate determination of the kilovoltage becomes impossible. Single, thin sparks, which often jump much farther, than the anticipated gap, are proofs of the presence of these high tension surges and indicate that the sphere gap measurement is unreliable. These surges do not influence the output of a tube but by rendering the sphere gap measurement uncertain they may indirectly cause differences in the intensity of the radiation.

Two types of rectification are in common use. The first applies only one-half of the alternating wave to any one tube and either applies the other half to a second tube or wastes it altogether if only one tube is used. This type is called single wave rectification. The second type rectifies both halves of the wave and applies them to a single tube, or to two tubes connected in parallel.

Theoretically, there should be no great difference in efficiency between single and full wave rectification. A current of 5 milliamperes through the tube means an *average* value of 5 milliamperes. In the case of single

wave rectification an average value of 5 milliamperes is produced by pulses of high peak value, with periods of no current transmission between; in the case of full wave rectification the peak values are much lower but the number of pulses occurring per second are doubled. In the first case, the peak value may be 12 milliamperes but the current flows only half of the time; in the second case the peak value may be about 6 milliamperes and the current flows practically all of the time. Nevertheless, it is found that the two types do differ in efficiency by about 10%. This is due to the fact that the intensity does not increase in direct proportion to the millamperage. When the peak milliamperage is high, the wave form is not so favorable; the efficiency is improved if the current flow is distributed over a longer period. It has been observed that the maximum safe milliamperage with single wave rectification is lower than with full wave rectification. If the safe limit is exceeded, the milliamperage suddenly increases, and equilibrium can only be attained again by cutting down the filament current.

Another factor to be taken into account in considering the production of the Roentgen rays is the magnitude of the rectifier arc (the mechanical arc). As the rectifier arc is increased, the soft radiation component is increased. Conversely, however, no matter how small the arc is made, the soft ray component cannot be reduced to zero. The larger the rectifier arc, the smaller will be the tendency for sparking to occur and therefore the smaller will be the danger of high tension surges.

The best setting of the rectifier is attained when only a mild spark occurs at the make; arcing at the break should be avoided as it results in a very unsteady operation of the tube and shortens its life.

Ex. 4. How do new and used Coolidge tubes or well evacuated and poorly evacuated Coolidge tubes differ in the production of Roentgen rays?

The chief advantage of the Coolidge tube over the gas tube is that both intensity and hardness can be held constant. However, in comparing various Coolidge tubes or even the same tube with itself after a long period of operation, first order differences will be detected in intensity. Differences in hardness with the heavy filtration used in deep therapy are always of the second order.

Well evacuated tubes give such consistent results, that no differences can be detected even with the most sensitive measuring instruments. Poorly evacuated, fluorescent tubes, which periodically give off gas, and tubes which can be held at a constant milliamperage only by special efforts, may show considerable variation from the normal intensity and in exceptional cases may go as much as thirty per cent below the normal intensity. Even good tubes, which have been in service for a long period finally show a diminished intensity; this is caused by the pitting of the target and a greater partial absorption of the rays emanating from it as well as by selective absorption of the rays by the tungsten deposit on the walls of the tube. After 500 hours of operation the intensity has been decreased 10 to 15%; in one case of more than 1000 hours of operation the intensity was 23% below normal. Accordingly, the time of exposure must be increased 10 to 20% to achieve the same results as with new tubes.

Ex. 5. ½ millimeter of copper and ¾ millimeter of copper instead of 1 millimeter of copper are used.

The intensity is not a simple function of the filtration. The effect of the filter depends largely on the composition of the beam, that is on the relative amounts of hard

and soft rays. The composition of the beam in turn varies greatly with operating conditions and depends in particular on the transformer and rectifier used. Hence, only a few special cases can be treated and it must be understood that the data given below is not valid for the general case.

At 200 K V the intensity changes approximately 23% on passing from 1 millimeter of copper to ¾ millimeter of copper; and 60%, on passing from 1 millimeter to ½ millimeter of copper. At 150 K V the differences are more marked. On passing from 1 millimeter to ¾ millimeter the intensity changes 26%. On passing from 1 millimeter to ½ millimeter the intensity changes 74%.

As a rough approximation the following rule can be given for the two kilovoltages under consideration:

In changing from 1 millimeter to ¾ millimeter the intensity changes 25% or ¼.

In changing from 1 millimeter to ½ millimeter the intensity changes 67% or 2/3.

The corresponding treatment times are calculated as follows: If the intensity is increased by ¼ or in the ratio of 4 : 5, the treatment time must be cut down in the inverse ratio, namely 5 : 4, that is, the time must be decreased by 1/5.

In the second case the intensity is increased by 2/3 or in the ratio of 3 : 5. The time must be cut down in the ratio of 5 : 3, that is, the time must be decreased by 2/5.

In Fig. 2 the results of physical and biologic measurements are given graphically in a series of curves. The figure shows the intensity as a function of kilovoltage and thickness of filter. The intensity at 200 K V, and 4/4 millimeters of copper is arbitrarily taken as 100.

The ordinates represent intensities; the abscissæ

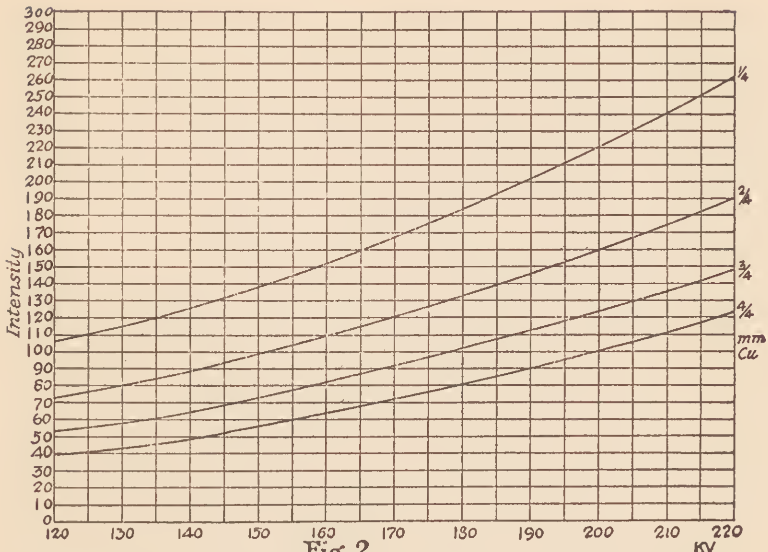


Fig 2

Intensity as a Function of Kilovoltage for Various Filters.

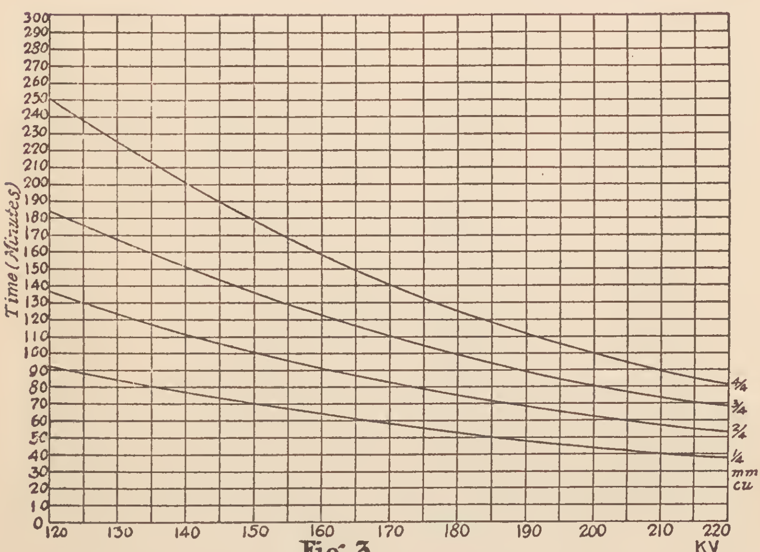


Fig. 3

Erythema Time as a Function of Kilovoltage for Various Filters.

voltages; each curve represents a certain filter thickness. Kilovoltages are compared by running along any curve; filters by passing from one curve to another. If the intensity corresponding to one kilovoltage and one filter thickness is known, then this series of curves makes it possible to deduce the intensity corresponding to any other voltage and any other filter thickness.

The curves in Fig. 3 are of still greater importance. These show the time of radiation as a function of the kilovoltage and the filter thickness. For simplicity the time corresponding to 200 K V and 1 millimeter of copper is put equal to 100. The change in treatment time expressed in per cent can be read off directly from these curves for any change in kilovoltage or filter thickness.

A similar series of measurements has been carried out by Fallia and Quimby with 140 K V and various thicknesses of brass and aluminum filters. The results were as follows:

Percentage of radiation transmitted	Brass filtration	Aluminum filtration	Ratio $\frac{\text{Aluminum}}{\text{Brass}}$
100 %	0 mm	0 mm	....
25.6 %	.15 mm	4 mm	26.6
22.2 %	.20 mm	5 mm	25.0
19.5 %	.25 mm	6 mm	24.0
16.0 %	.34 mm	8 mm	23.0
13.5 %	.43 mm	10 mm	23.2
11.8 %	.53 mm	12 mm	22.6
9.0 %	.77 mm	16 mm	21.8
7.1 %	1.05 mm	20 mm	19.1

Ex. 6. The focus skin distance is increased from 50 to 60 centimeters.

The physical law which applies to this case is as follows:

The intensity is inversely proportional to the square of the distance. If the distances are in the ratio of 50 : 60, or 5 : 6, which is the same thing, then the corresponding intensities are in the ratio of 36 : 25.

If the intensity at 50 centimeters be taken as 100, which again is a convenient figure for calculating in terms of percentages and if, further, the intensity at 60 centimeters be taken as X, we have the equation

$$100 : X = 36 : 25$$

from which $X = 2500 : 36 = 69.5$

The intensity at 60 centimeters is therefore about 70% of that at 50 centimeters.

It is easier to determine the ratio of the corresponding treatment times directly. The exposure times vary inversely as the ratio of the intensities: a smaller intensity means a longer exposure. The law of inverse squares can be restated:

The treatment time varies directly as the square of the focus skin distance. If as before we take the time corresponding to 50 centimeters equal to 100 and call the unknown time t, we have the equation

$$t : 100 = 36 : 25$$

therefore

$$t = \frac{3600}{25} = 144$$

The time of radiation must therefore be increased 44% if the focus skin distance is changed from 50 centimeters to 60 centimeters. The same holds for the milliampere-minutes: instead of 600 milliampere-minutes, 864 milliampere-minutes must be applied.

A question of practical importance is what a small

error in the focus skin distance makes in the intensity. For this calculation we shall apply the principle we have used once before, namely, if two numbers differ by a small percentage, then their squares differ by double this percentage.

Suppose we make an error of 2½ centimeters (1 inch) in making the 50 centimeter setting. This is an error of 5%; the time of radiation will then be in error by double this amount of 10%. If the error is made in the sense that too large a focal distance is used, it would mean that the time of exposure needs to be increased by 10%. Unless this is done the region treated is slightly under-exposed. If the error is made in the opposite direction, then the region treated is slightly overexposed.

An error of plus or minus 10% can hardly be detected biologically and is therefore not of great importance.

However, an accidental error of 5 centimeters (10%) in the setting would mean an intensity difference of 20% and this represents a dosage error which would very likely make itself manifest by its consequences.

In the literature the question of whether the law of inverse squares is rigorously true has often been raised. This question will be answered in the following example dealing with the scattering of the Roentgen rays. It may be here answered, that for all practical biological purposes the law of inverse squares is valid.

Ex. 7. The size of the field is to be changed from $(20 \text{ cm})^2$ to a smaller value. How will this effect the dosage?

The energy radiated to a surface layer of a body consists of two components: the primary radiation coming directly from the source of the rays and the secondary radiation scattered back by the interior of the body. The latter component depends on the volume traversed by

the radiation. The greater this volume, the greater is the energy which is scattered back. With hard rays and a port of entry of 20 cm × 20 cm—a relatively large field—about 50% of the incident energy is scattered back. The following experiment shows this very clearly:

An instrument which measures both secondary and primary radiation—for best results a small ionization chamber of a type which will be discussed in detail later—is put in the path of the direct beam, first without any absorbing or scattering bodies in the neighborhood, and second, with a large water phantom, preferably a cube 25 cm on a side, placed underneath. Figure 4.

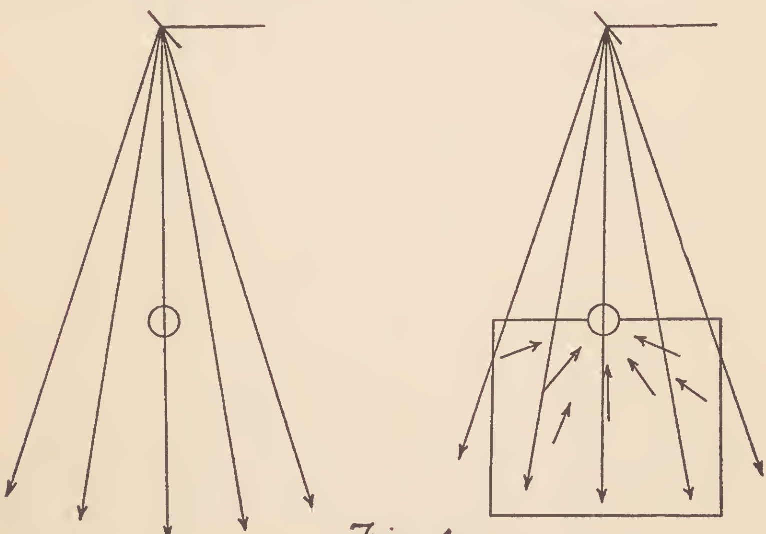


Fig. 4.

Effect of Scattered Radiation.

The ionization chamber in the latter case should be half immersed in the water. If in the first case the intensity is found to be 100 then in the second case it will be approximately 150—the increase being due entirely to

energy which is scattered back by the water within the cube. The amount of scattered radiation depends to a high degree on the volume which is being traversed by the radiation. If a narrow beam is sent into the water, then only a small volume can radiate secondary rays back to the surface. Then primary energy alone is present at the surface. Exact measurements show the following relation between the intensity and the size of the field; the intensity for a field 20 cm × 20 cm is taken equal to 100. The following table gives the various intensities together with the corresponding times which are necessary in order to produce the same biological reaction. The last column gives, in addition, the milliampere-minutes under normal operating conditions.

Size of Field	Intensity	Time	Energy
20 × 20 cm^2	100%	100%	600 M A min
15 × 15 cm^2	95%	105%	630 M A min
10 × 10 cm^2	87%	115%	690 M A min
5 × 5 cm^2	77%	130%	780 M A min

For fields greater than 20 cm × 20 cm the intensity is not appreciably greater; with a field of 20 cm × 20 cm the scattered component attains a practical maximum.

On account of the addition of the scattered component, the inverse square law is somewhat modified when large volumes are rayed. The energy in the interior is increased by an increase in focus skin distance as well as by an increase in size of field. Since part of this energy is returned to the surface, the latter also receives a larger supply of energy. If the focus skin distance is changed from 30 centimeters to 60 centimeters the intensity at the surface ought to decrease to ¼ of its value at 30 centi-

meters. It is found, however, that due to the more favorable distribution at 60 centimeters, a larger intensity is scattered back to the surface than was the case for 30 centimeters and the intensity at 60 centimeters does not fall in ¼ its value at 30 centimeters.

According to measurements made by the author the intensity falls to 27% rather than to 25%. However, the deviation from the inverse square law is so small that in practice it is of little importance.

Ex. 8. With apparently normal conditions, for some reason or other, say on account of a poor transformer, a low kilovoltage, a low milliamperage, let the intensity be low and the time of radiation too lengthy. The time of radiation is to be decreased from say 180 minutes to a more favorable time.

Which factor is to be changed to obtain a shorter exposure time?

(a) It is often possible to increase the kilovoltage from 200 to 210 or 215 K V without danger to the tube. This can be done in the following special cases:

Limited capacity transformer.

Single wave rectification.

Absence of surges.

Care must be taken that the tube does not fluoresce too brilliantly, that it does not crackle, and that the milliammeter does not show spasmodic increases in current. All these phenomena are indications that the danger point has been reached and that the kilovoltage is too high.

(b) Often the milliamperage can be increased, for example, in the following cases:

When the kilovoltage is low, which may occur in regions of low barometric pressure like Denver, Colorado Springs, Pueblo; when transformers of low efficiency

[not, however, when used with single wave rectification] are employed; when the new tubes designated "200 K V, 8 milliamperes" are used; and when the tube is well cooled by an air blast from a blower or suction pump.

Care must be taken that the tube does not overheat, that the anticathode does not bend and that gas is not given off. The presence of gas is indicated by a hissing sound, by an increase in milliamperage and a decrease of kilovoltage.

(c) Sometimes the rectification can be improved.

(d) Occasionally, the cause for low intensity is a tube which has been used too long or has developed gas.

(e) In many cases the thickness of the filter is incorrect. Some copper filters, which are stamped "1 millimeter" actually have a thickness of 1.2 millimeters. If the patient is treated from below (on a couch), a mattress, a sheet, or even a wooden board is often interposed. All these substances show appreciable absorption. Mattresses frequently absorb 10 or 12%; a layer of wood equally as much. The time of exposure is accordingly unduly increased. These conditions can be remedied in the following ways:

A smaller copper filter, perhaps ¾ or ½ millimeters of copper, can be used on account of the fact that the other substances also act as filters; the aluminum filter can be omitted since the characteristic rays from the copper are absorbed by the substances placed over it. Balsa wood, which absorbs about 1/10 as much as any other wood and still has sufficient mechanical strength even in 2 cm. thicknesses can be used. An air cushion also can be inserted into an aperture made in the mattress.

By the use of one or more of these devices, the exposure time can be considerably shortened. From the laws

and illustrations already given, an estimation of the new radiation time can be made.

(f) In very unfavorable cases when none of the above remedies can be applied, the focus skin distance can be decreased. In this way the exposure time can be greatly shortened; but the distribution of dosage in the interior of the body is not so favorable as will be shown later.

(g) An increase in size of field is not of practical importance for increasing the surface intensity, but it can be used to attain a better depth distribution as will be shown later.

By a correct combination of these various factors the exposure time can be made fairly agreeable to the patient even in very unfavorable cases. The preceding detailed discussion of the many factors which influence the milliamperage shows that an estimation of the energy which a patient receives is possible by the indirect method only if all the various factors are accurately known.

This usually is not the case when two Roentgen ray installations are to be compared. Apparatus and conditions of operation are so widely different in practice that a milliampere minute measurement is absolutely worthless.

A few examples will serve to illustrate this.

(1) With apparently normal conditions 200 K V, 1 millimeter of copper plus 1 millimeter of aluminum, 50 cm. focus skin distance, 720 milliampere minutes did not produce an erythema. Careful measurements showed that the kilovoltage was only apparently 200 K V due to high voltage surges, which were produced by a poor

adjustment of the rectifier with attendant sparking. An adjustment of the rectifier followed by a boosting of the kilovoltage produced the correct intensity, so that an erythema was produced by 600 milliampere minutes.

(2) In one hospital it was found that 720 milliamperes (occasionally 900 milliamperes) could be applied without producing a heavy erythema. The question of how this could be possible was asked of the author many times. Therefore careful measurements of the conditions were made. The results were as follows:

(a) With really normal operating conditions, the apparatus was 12% below normal.

(b) The voltage actually used was only 193 K V.

(c) A thick, leather sheet was inserted, which absorbed 13%.

The intensity under these operating conditions was therefore 28% below normal. Nine hundred milliampere minutes really corresponded to 650 milliampere minutes and was not really out of the ordinary. These examples show that it is erroneous to apply the milliampere minutes used by one installation without further thought to another installation. A factor of safety of 20% should always be used in the beginning until the erythema dose has definitely been measured.

On the other hand, the milliampere minute value is very useful in the operation of one and the same installation after the operating conditions are known and as long as they are kept constant or varied according to well known laws. The application of low, normal, or high energies measured out in terms of milliampere minutes is a convenient and sure method of dosage.

If, in addition to the other factors, the milliamperage is not changed, it is possible to use the simple method of treating with the time clock—a mechanical and accurate method of dosage.

The indirect method of dosage is more favorable in the case of radium therapy than it is with Roentgen rays. The great advantage in the case of radium radiation lies in the constancy of the source. The intensity depends on fewer and more readily measured quantities. The latter are:

1. The amount of radium in milligrams.
2. The time.
3. The concentration.
4. The filtration.
5. The focus skin distance.

The factors 1, 3, 4, and 5 determine directly the intensity of the radiation; the time factor determines the total quantity of energy applied. Milligram hours in radium therapy correspond to the milliampere minutes in Roentgen therapy. The following should be observed in connection with the factors enumerated.

(1) The quantity of radium: the number of milligrams of the element.

For the sake of standardization and ready comparison calculations should not be made in terms of radium bromide, radium chloride, radium sulphate, radium carbonate, etc., but in terms of the quantity of the element present in these compounds. The following factors can be used for this calculation:

1 mg $Ra\ Cl_2$	$=$ 0.761 mg Ra element
1 mg $Ra\ Br_2$	$=$ 0.585 mg Ra element
1 mg $Ra\ Br_2 + 2H_2O$	$=$ 0.536 mg Ra element
1 mg $Ra\ SO_4$	$=$ 0.702 mg Ra element
1 mg $Ra\ CO_3$	$=$ 0.790 mg Ra element

(2) The time is given in hours.

The product of milligrams of radium element and time determines the energy applied to the tissues. It must be added in this connection that observations made by some German and American scientists indicate that the biologic effect is not entirely independent of the separate factors: milligrams of radium and hours of exposure. We shall come back to this subject in a later chapter; for the present it may be stated that for the quantities and times ordinarily used no very serious errors are made by assuming that the biologic reaction depends only on the product of the two.

(3) It often happens that the concentration of the radium rays is ignored. The importance of this quantity may now be made clear.

Let us consider two cases:

Case 1. A surface is treated with one 25 milligram capsule for 10 hours. A certain reaction will result.

Case 2. Two 25 milligram capsules are placed parallel a short distance apart in the same region as above and the same total number of milligram hours is given—that is, the treatment is continued for 5 hours. In this case the biologic effect will be approximately half of what it was in the first case although the same number of milligram hours have been applied. The amount, however, has in the second case been applied to two practically

separate areas. In order to produce the same reaction as with the single capsule the number of milligram hours must be nearly doubled. Only after the milligram hours have been doubled will each region show the same biologic effect. It is therefore misleading to state the total number of milligram hours unless the number of areas treated is also given. In other words, the number of milligram hours per unit of surface treated, namely the *concentration* of energy, is the primary factor.

Plainly, we are concerned here chiefly with the reaction of the surface layers; at a depth of 5 cm. the energies do add in the expected way and the dosage at a depth of 5 cm. is the same in both of the cases cited above.

This distribution of the energy over the surface layers is similar in the principles to the multiple field method of Roentgen ray therapy. By this method a favorable intensity is produced at a considerable depth without overexposing the surface layers. Acting on this idea Wilhelm Stenstrom has devised an apparatus which, provided a sufficient number of radium preparations are available, makes it possible to produce an intensity at a depth of a few centimeters greater than the intensity at any point of the skin.

In treating with several radium needles each single needle determines the intensity in its immediate neighborhood; a short distance away, however, the effects of the various needles overlap and add; and a stronger reaction is produced by the use of a number of needles with a proportionately larger number of milligram hours.

The magnitude and distribution of the energy resulting in such cases will be taken up in detail later.

The effect of the concentration is very noticeable when superficial regions are treated with radium plaques. For example, if three plaques of different sizes: 1, 2, 4 centimeters square but with the same number of milligrams of radium are applied for equal lengths of time, the biologic effects will be in the ratio of 4 : 2 : 1. In the first case, that of the smallest field, the same intensity is concentrated on a smaller surface than in the second and third cases. The terms double strength, full strength, and half strength may be used. If the same effect is to be produced in all three cases, the exposure times must vary as 1 : 2 : 4; or, with equal exposure times, the concentration (not the total quantity of radium) must be kept the same. That is: the three plaques must have full strength:

The 1 square centimeter plaque — 5 milligrams,
The 2 square centimeter plaques—10 milligrams,
The 4 square centimeter plaques—20 milligrams.

Then each square centimeter will receive the radiation emanating from 5 milligrams of radium and, if the exposure time is the same, will receive the same quantity of energy. This, of course, is not rigorously true for the reason that the phenomenon of scattering comes into play much as it does with large ports of entry in the case of Roentgen rays. Since, however, as will be shown later, the intensity decreases very rapidly with the distance when radium is used for treating surface lesions, the quantity of scattered energy is not very large. The effect of the size of the field is not so important with radium rays.

(4) The filtration.

The intensity of the radium radiation depends to a high degree on the filtration used. This is due to the

fact that the radiation is composed of very different hard rays and that the soft components make up a large part of the total energy.

The intensities of the alpha, beta and gamma rays, measured biologically, vary approximately in the ratio of 10,000 : 100 : 1.

The alpha rays usually are absorbed before they reach the tissues and therefore are of minor importance.

The beta rays are the active component in the case of unfiltered or lightly filtered preparations and produce strong biologic effects.

The gamma rays alone remain if heavy filtration is used but in comparison with the beta rays their biologic action is very mild.

The following example shows the dependence of the erythema exposure time on the filtration.

Ten milligrams of radium element placed in a radium needle of non-corrosive steel produce a definite erythema in 20 minutes, if the needle is placed directly on the skin. In this case part of the beta rays are effective. If the same preparation is filtered through 1½ millimeters of brass so that the beta rays are absorbed, 2 hours are necessary to produce the same reaction. If the contents of the needle were placed without filtration directly on the skin, 2 minutes would be sufficient to produce an erythema.

The effect of the filtration on the intensity of radium radiation has been investigated very thoroughly by Failla and his coworkers: Quimby and Dean. The intensities were measured biologically; the experiments therefore are analogous to those made by Failla and by the author on Roentgen radiation.

If the intensity of an unfiltered preparation (say a

small glass tube containing radium emanation) is taken as unity, the following numbers indicate the intensities obtained with various thicknesses of brass filters, all other factors remaining the same:

Brass	Rubber	Intensity
0 mm	0 mm	1.00
0.1 mm	1.2 mm	0.62
0.2 mm	1.2 mm	0.26
0.3 mm	1.2 mm	0.085
0.4 mm	1.2 mm	0.050
0.5 mm	1.2 mm	0.030
0.6 mm	1.2 mm	0.021
0.8 mm	2.4 mm	0.0145
1.00 mm	2.4 mm	0.0119
1.25 mm	2.4 mm	0.0105
1.50 mm	2.4 mm	0.0098
1.75 mm	2.4 mm	0.0094
2.00 mm	2.4 mm	0.0090

Figure 5 shows these relations graphically. From the intensity corresponding to any one brass filtration, the

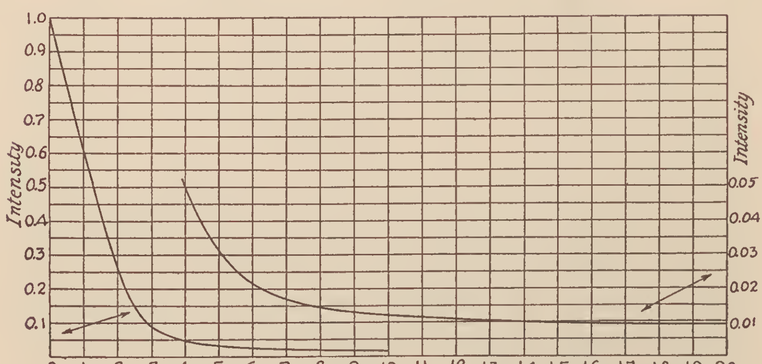


Fig. 5

Effect of Filtration on Intensity of Radium Rays.

intensity corresponding to any other can be deduced by comparing the indicated values. The curve shows the relatively strong filter action of thin glass, which absorbs a large fraction of the alpha, beta and soft gamma rays. Beyond 1.5 mm of brass only a very slight change in intensity is observed on account of the extreme penetration of the residual gamma rays.

The equivalence of various filter materials has been investigated by Quimby, again with reference to the biologic effect. The following table gives the results for aluminum, brass and lead in equivalent millimeters:

Aluminum	Brass	Lead
0.60 mm	0.16 mm	0.08 mm
1.20 mm	0.32 mm	0.16 mm
1.74 mm	0.48 mm	0.25 mm
3.34 mm	0.96 mm	0.58 mm
6.11 mm	1.92 mm	1.10 mm
10.78 mm	3.04 mm	1.33 mm

The values given by Friedrich and Kroenig do not agree very closely with those of Quimby, due probably to differences in the methods of measurement; according to the former

9.5 mm aluminum
1.5 mm brass
.8 mm lead

are equivalent.

With the help of these relations it is easy to change from one material to the other. Silver filters a little more strongly than brass but the differences are negligible. The substance used for radium needles, namely non corrosive steel, is an alloy which behaves very similiar to brass.

(5) The same law of distance holds for radium rays as for Roentgen rays. The intensity varies inversely as the square of the distance.

One important difference, however, must be noted. With a Roentgen ray tube the focus skin distance is always so large in comparison with the dimensions of the focal region that the law of inverse squares holds very exactly. In dealing with radium rays, the focal distances are of the order of a few millimeters (occasionally a few centimeters); hence we can no longer treat the preparation as a point source. The radiation reaching any given point is the sum of the radiations emanating from a series of points to each of which there corresponds a different focal distance. We can no longer speak of a single focal distance since this is not uniform. Thus the law of inverse squares cannot be directly applied. For a point on the skin adjacent to the preparation the intensity is smaller than would correspond to the law of inverse squares. The actual relation between intensity and distance can be calculated from the geometrical shape of the preparation; it has, moreover, been determined experimentally for most preparations and arrangements used in practice. The greatest number of observations were made by Quimby. The values obtained have reference to an average erythema: "a very low reaction defined as the erythema produced on the skin of the average patient by a dose of 7.5 mc hrs of ungltered radiation, applied at a distance of 2 cm. By unfiltered radiation is meant the radiation from the emanation in the capillary glass tube with no additional covering."

The accompanying tables are extracts from the wealth of data obtained by Quimby, except that the

	No filter				0.16mm brass + 1.2mm rubber				0. 35 mm alloy + rbbr.	0.5mm brass + 1.2mm rubber					1 mm brass + rbbr.	1.5 mm brass + rbbr.	2mm brass + 2.4mm rubber				
	Emanation Tube	Square			Tube	Square			Needle	Tube		Square			Tube	Tube	Tube		Square		
Cm Distance	Point	$(1cm)^2$	$(4cm)^2$	$(10cm)^2$	1cm	$(1cm)^2$	$(4cm)^2$	$(10cm)^2$	1cm	1cm	2cm	$(1cm)^2$	$(4cm)^2$	$(10cm)^2$	2cm	2cm	1cm	2cm	$(1cm)^2$	$(4cm)^2$	$(10cm)^2$
0.05	....	[0.16]	[1.0]	[6.2]	[0.2]	[1.2]	[19]	[90]	(2)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0.10	[0.02]	[0.2]	[1.6]	[6.7]	[0.3]	[1.4]	[20]	[95]	(2.5)	[6]	[14]	[11]	[120]	[620]	.....	.....	.....	.....	.....	.....	.....
0.25	0.1	0.33	2.1	8.3	1	1.75	21	98	(6)	11	22	20	150	650	(50)	(60)	.....	.....	.....	.....	.....
0.50	0.5	0.75	3.1	11	3	2.7	25	115	(17)	26	42.5	36.5	200	870	(100)	(120)	.....	.....	.....	.....	.....
1	2	2.3	5.3	16.4	7	6.6	28	151	(42)	77	105	88	315	1250	(250)	(280)	240	285	265	600	2000
2	8	8.3	12	27	21	21.6	43	167	.....	285	310	285	590	1660	(750)	(900)	900	950	930	1420	3130
3	18	18.3	22	40	47	46	69	.....	.....	620	666	620	900	2220	(1500)	(1800)	2000	2000	2000	2600	4600
5	50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5550	5550	5550	6250	8700
7.5	112	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12500	12500	12500	13300	16600
10.	200	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	20000	20000	20000	22000	25000
cm	mg hrs.																				

author has calculated the number of millicurie hours which produce the same average erythema under different conditions of filtration, kinds of preparation, distances, etc. A number of values were extrapolated for the case when the preparation is in direct contact with the skin; these values are not found in the data given by Quimby and have been enclosed in brackets in the table; other values are obtained by interpolation and are indicated by enclosing them in parenthesis.

All the values given refer to the geometric center of the preparation, or, as the case may be, to the central ray. In passing outward from the center or toward the edge the intensity rapidly decreases, falling off the more rapidly the nearer the preparation is placed to the skin. Very close to the plaques, the intensity at the edge is about half that at the center. At a distance about twice the diameter of the preparation the intensity is the same over the whole width of the preparation. Outside of this region the intensity decreases appreciably.

The average erythema of Quimby (Memorial Hospital of New York) is very low; in a series of cases an erythema does not occur at all; for this reason the value has been increased from 7.5 mc hrs to 8 mc hrs. This is done also for another reason, namely, that the intensity of a radium preparation always appears lower than that of the emanation, since the radium salt absorbs more strongly than the emanation.

In the following table the erythema times given by the Radium Company of Colorado for their preparations when the latter, with the filters indicated, are used directly on the skin.

25 mg tube, ½ mm silver + rubber dam, 20-30 min = 8-13 mghrs.

50 mg tube, ½ mm silver + rubber dam, 15-20 min = 12-17 mghrs.

12.5 mg needle, noncorrosive steel + rubber dam, 15-25 min = 3-6 mghrs.

10 mg needle, noncorrosive steel + rubber dam, 20-30 min = 3-5 mghrs.

5 mg needle, noncorrosive steel + rubber dam, 30-45 min = 3-4 mghrs.

$$\left.\begin{array}{l}\text{Double strength plaque, no filter, rubber dam, 1.5 min =}\\ \text{Full strength plaque, no filter, rubber dam, 3 min =}\\ \text{Half strength plaque, no filter, rubber dam, 6 min =}\end{array}\right\}\frac{0.25\text{ mghrs}}{\text{cm}^2}$$

The values given in the two tables agree fairly well. For a tube with ½ mm brass (or silver) placed directly on the skin the first table gives a value of 14 milligram hours; the second from 8 to 17 milligram hours. For ordinary needles without additional filtration, placed directly on the skin, again the first table gives 2 milligram hours, the second (with rubber dam) 3 to 6 milligram hours. For unfiltered radium plaques according to the first table about 0.1 milligram hours per square centimeter on the average are required; according to the second (with rubber dam) 0.25 milligram hours are required.

Very frequently tubes about 2 centimeters long with 1.5 mm brass filtration are used, since these practically absorb all the beta rays. If the customary doses for a distance of 3 cm between the geometrical center of the

preparation and the skin are compared, the following results are obtained:

Failla, Quimby ....1800 mghrs.
Seitz and Wintz ....3000-3600 mghrs.
Friedrich ....5500 mghrs.
Bumm, Schauta, Adler ....6000 mghrs.
Kehrer..........10,000 and more mghrs (interrupted).

All the values greater than those of Seitz and Wintz produce stronger reactions than an erythema; the values of Friedrich produce blistering of the skin and a crust formation, which restitues ad integrum after one or two months. In the author's opinion 2500 milligram hours at 3 cm produce a reaction within the tissue corresponding to a very low erythema. 5000 milligram hours, however, produce a reaction, which corresponds to a well defined erythema with blistering of the skin. On the basis of these values the iso-dosage lines for radium preparations have been drawn, which are to enable a comparison with Roentgen radiation.

In the following a few doses, with a statement of the corresponding reaction, have been compiled from the literature. (Authorities: Seitz and Wintz, Friedrich, Simpson, Newcomet and others.)

Needle, directly on the skin, 2 mghrs, low reaction.

Needle, directly on the skin, 5 mghrs, erythema.

Needle, directly on the skin, 10 mghrs, sharp reaction.

Needles, in the tissues, at a distance of 1 cm, 60 mghrs, low reaction.

Needles, in the tissues, at a distance of 1 cm, 100 mghrs, normal reaction.

Needles, in the tissues, at a distance of 1 cm, 125 mghrs, sharp reaction.

5 needles in 1 mm brass tube, directly on the skin. 100 mghrs, low reaction; 175 mghrs, sharp reaction.

5 needles, in 1 mm brass tube, 1 cm distance, 500 mghrs, low reaction; 750 mghrs, sharp reaction.

5 nedles, in 1 mm brass tube, 2 cm distance, 1500 mghrs, low reaction; 2500 mghrs, sharp reaction.

5 needles, in 1 mm brass tube, 3 cm distance, 3000 mghrs, low reaction; 5500 mghrs, sharp reaction.

50 mg tube, ½ mm silver and rubber, 17 mghrs, low reaction; 150 mghrs, sharp reaction.

10 mg full strength plaque, no filter, 0.25 mghrs/cm^2, low reaction; 1 mghrs/cm^2, sharp reaction; 2.5 mghrs/cm^2, destructive dose.

10 mg full strength plaque, 0.1 mm lead, 1.2 mghrs/cm^2, no reaction; 5 mghrs/cm^2, low reaction.

10 mg full strength plaque, 0.2 mm lead, 7.5 mghrs/cm^2, low reaction; 12.5 mghrs/cm^2, strong reaction.

10 mg full strength plaque, 1 mm silver, 2 mm rubber, 150 mghrs/cm^2, sharp reaction.

The minimum values, which produce an erythema and occasionally vesication or ulceration, as determined with 25, 50, 100 milligram radium element in a tube with 1 mm lead plus a rubber sheet, are given by Newcomet as follows:

Intimate contact, 100 mghrs.

1 cm, 200 mghrs.

Also the statement in "New and Non-Official Remedies" of the American Medical Association that an erythema is produced by 1,000 milligram hours, 2 mm lead, surface (2.5 cm)^2, distance 2.5 cm refers to a mild erythema.

With the help of these values, especially those given

in the first table the treatment factors in milligram hours can be determined for any desired reaction and any preparation used in practice.

According to Failla, a formula can be given from which the intensity of the radiation can be determined for any preparation. The formula is:

$$I = \frac{0.63 \times \text{mghrs} \times \delta \times \alpha}{r^2}$$

0.63 is a constant factor.

(r) is the distance from the center of the preparation.

(δ) is the distribution factor, which is unity for a point source and less than 1 for one of finite dimensions.

(α) is the filter coefficient.

(I) is the intensity, which is set equal to 1 for an average erythema.

The formula is of great practical use if the necessary data on α and δ, which are somewhat interdependent, are known. Since, however, the tables already given indicate the exposure times directly, we shall not discuss the formula in greater detail, but shall refer the reader to the original articles of Failla and Quimby in the Journal of Roentgenology of 1920 and 1922.

For the determination of the exposure time for radium preparations, such as radium needles and radium capsules, the following curves are important: The curve of Figure 6 shows how the biologic effect depends on the distance between the axis of the needle and the surface of the skin. The biologic effect is given in terms of a biologic scale. A well defined erythema is designated by the number 100; 50 therefore means half an erythema dose. The curve gives a biologic effect (vertical axis) for every focus skin distance (horizontal axis); it is correct for radium needles used without additional filtra-

tion, when 5 milligram hours are applied, as well as for radium needles filtered with ½ mm of copper or brass, when 25 milligram hours are given, and finally for filtration of 1 mm of copper or of brass when 35 milligram

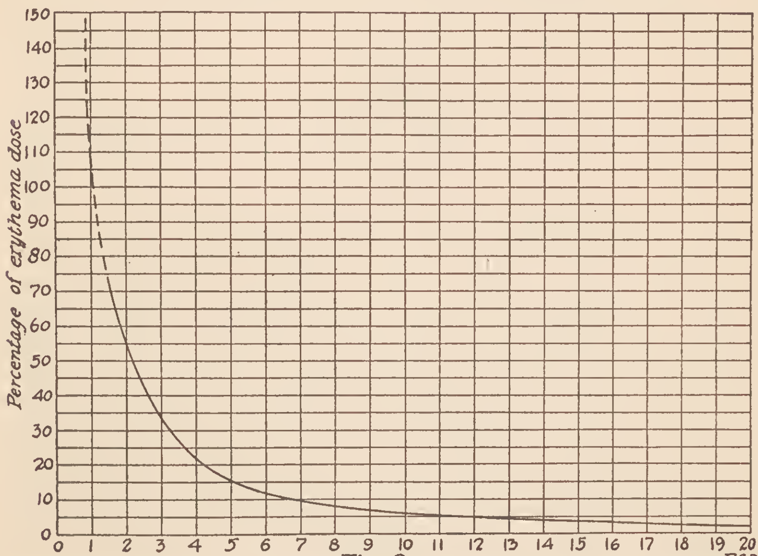


Fig. 6

Distribution curve of a radium needle in the air, for the determination of the erythema time with one or more needles.

No additional filtration, 5 (2.5) mghrs,
0.5 mm cu added, 25 (12.5) mghrs,
1.0 mm cu added, 35 (18) mghrs,
Erythema dose designated by 100.

hours are applied. If these filtrations and milligram hours are used, then according to the curve for a distance of 1 mm 100 is a dose which produces a well defined erythema; for 2 mm, 55 is approximately one-half of this dose, and for 3 mm, 33 is approximately one-third of this dose.

If in the last case a full erythema is to be given the number of milligram hours is to be multiplied by 3, hence, 15, 75, 105 milligram hours, respectively, are required.

With the help of these values the effect of preparations composed of a number of needles can easily be determined. If for example a plaque is made up of 5 needles which are spaced 2 millimeters apart on the skin as in Figure 7 then we obtain the following result for

Fig. 7.

Calculation of Dose, Five Radium Needles.

the center of the rayed surface. When 5 milligram hours without auxiliary filtration are applied, then this point receives from the center needle at a distance of 2 millimeters, 55 units; from the two adjacent needles at a distance of nearly 3 millimeters, 2 × 33 or 66 units; from the two outside needles at a distance of 4.5 millimeters 2 × 18 or 36 units; or a total of 157 units, that is to say, about 1½ times an erythema dose. If this dose is too high, then by ⅔ of this number of milligram hours a well defined erythema can be produced; if in the case of an epithelioma a double erythema dose is to be given, then ⅓ more energy must be applied.

The effect at the edge of the region can also be determined:

1st needle,	2 millimeters distance...	55
2nd needle,	3 millimeters distance...	33
3rd needle,	4.5 millimeters distance...	18
4th needle,	6 millimeters distance...	12
last needle,	8 millimeters distance...	8
		126

The dose is therefore lowered by ⅕.

The same calculation can be carried out for the case of auxiliary filtration; in this case the stronger filtration of the rays which pass obliquely through the filter should approximately be taken into account; however, the error introduced by neglecting this effect is only a few per cent.

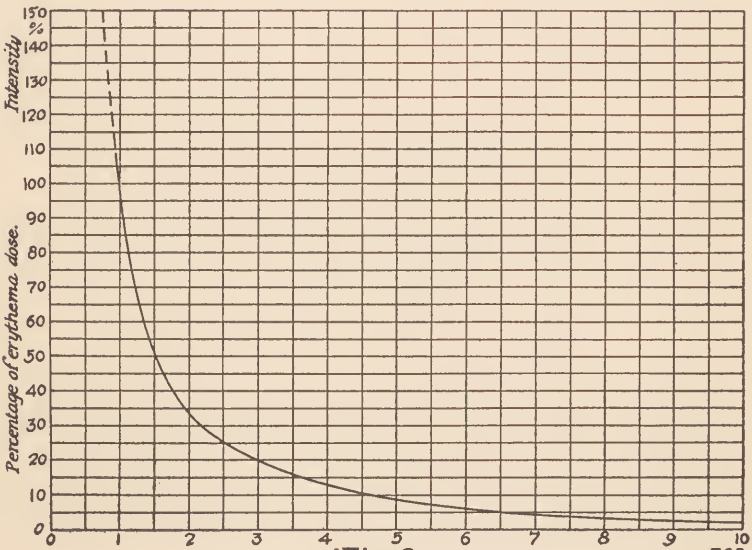


Fig. 8

Distribution Curve of a Radium Capsule in the Air, for the Determination of the Erythema Time with One or More Capsules. 1.5 MM Brass Filter, 500 (250) Mg Hrs Applied Erythema Dose Designated by 100.

Similarly with the help of the curve of Figure 8 the dose and the required exposure time can be determined for a single capsule as well as for a combination of several.

Let us assume that for raying an incision 5 centimeters in length, 6 radium capsules, each of which is placed at a distance of 2 centimeters from the skin, are

used. Figure 9 shows this arrangement. For the conditions illustrated in the figure the curve shows that the center of the field receives 2 × 31 or 62 units from the two central capsules at a distance of 2.1 centimeters;

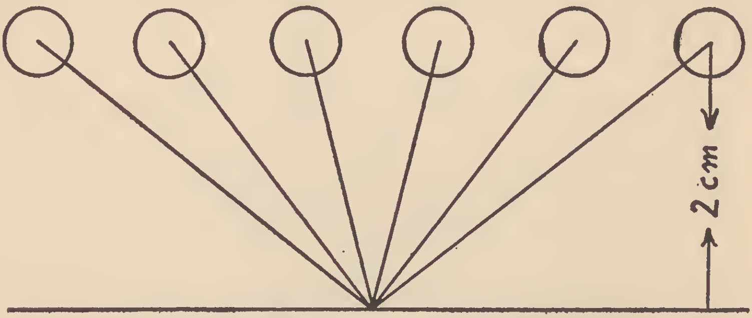


Fig. 9.

Calculation of Dose, 6 Radium Capsules.

from the two adjacent capsules at a distance of 2.5 centimeters, 2 × 25 or 50 units; and from the remaining two at a distance of 3.1 centimeters, 2 × 19 or 38 units; or a total of 150 units. Five hundred milligram hours with each capsule produces 1½ times an erythema dose; 333 milligram hours would therefore produce exactly an erythema. The question may be raised whether with this arrangement the surface is uniformly rayed. Let us therefore examine the intensity at a point directly under one of the central capsules.

From the one capsule at a distance of 2 centimeters it receives 33 units.

From the two capsules at a distance of 2.2 centimeters it receives 2 × 30 = 60 units.

From the two capsules at a distance of 2.9 centimeters it receives 2 × 21 = 42 units.

From the one capsule at a distance of 3.6 centimeters it receives 15 units.

Total 150 units.

The total is 150 or the same as for the other points; toward the edge the dose slowly decreases as can readily be determined.

Besides the application of radium rays by means of tubes, needles, and plaques, for small doses the following methods may be considered:

(a) Injection of solutions of radium.

(b) The drinking of radium solutions or solutions of radium emanation or the administering of pills and capsules which contain soluble radium salts.

(c) The inhalation of radium or thorium emanations.

(d) Bathing in water containing radium or radium emanation.

(e) Finally, radium compresses can be applied.

For injection only absolutely pure radium bromide or radium chloride in aqueous solution with sodium chloride can be used. Intravenous or intramuscular injections can also be made in the neighborhood of the diseased tissues. According to Gudzent about 5 micrograms of radium element should be injected every two days and on the average 15 or 20 injections should be made. .02 milligrams per week and a total of .1 milligrams are to be regarded as the maximum dose. The effect of an injection into muscular tissue may be conceived as a local reaction which gradually spreads out. In the case of intravenous injection the decomposition products of radium gradually accumulate in the blood forming organs, the marrow of the bone and the spleen. In all

these cases the active components are alpha and beta rays, hence the relatively large effect of small doses.

By bathing in water containing radium emanation the skin receives only a very minute quantity of radioactive material or of radiation, hence only strong springs are adapted for bath cures; in artificial baths the concentration should be about 250 eman per liter. About 5 micrograms must be added to a bath; the bath is to continue for about half an hour. The chief effect is due to the inhalation of air containing emanation during the bath. In some places precautions have been taken to make full use of the emanation escaping from the water; in Muenter am Stein the tubs are installed under the floor of the booths and so form a collector for the escaping emanation, which is heavier than air.

Radium compresses are similar in application and effect to surface applications, however, they contain very small amounts of radium, usually about 15 micrograms of radium element, hence they can only serve to apply very small amounts of beta and gamma radiations.

For drink cures solutions which contain about .01 milligrams of radium element can be used per day. In 4 to 6 weeks about 0.5 milligrams of radium can be administered to the body. The American Medical Association does not admit any preparations which apply less than 2 micrograms per day.

By drinking water containing emanation the same quantity, from 1 to 20 microcuries can be administered daily and the treatment can be extended over a period of six weeks. The action is at first cumulative on the stomach and intestinal tract but then is distributed over the body.

Inhalations are best made in closed rooms which con-

tain from 15 to 150 eman per liter. A sitting may continue for two hours and the total number may vary from 24 to 40. According to Ramsauer and Holthusen the emanation content of the blood rises during the first 15 minutes to about ⅓ of the concentration present in the surrounding air and then remains constant for the remainder of the sitting. Afterwards the emanation content decreases rapidly, the decomposition products are held by the body for some time and are gradually thrown off.

§3. Direct methods of measurement.

A direct method of measuring the intensity is defined as one which measures the energy of the beam directly.

Direct methods of measurement depend on the fact that Roentgen rays produce changes in bodies by which they are absorbed and that quantitatively these changes are proportional to the amount of energy absorbed.

These effects may be classified as:

(1) Thermal effects: expansion, change of resistance (bolometer), thermoelectricity.

(2) Chemical effects: discoloration, precipitation, change of resistance (selenium).

(3) Ionisation of gases: discharge of electrically charged bodies.

(1) Experiments with the heat effect of Roentgen rays have not resulted in any practical measuring devices. The thermal effect produced by Roentgen rays is minute; very sensitive instruments (air thermometer, bolometer, thermopile) must be used. Measurements carried out with these devices have shown that nearly all the energy of the electrons which strike the anticathode is transformed into heat and that only about 1/1000th of the incident energy is converted into Roentgen radiation. The

fractional part of the total energy transformed into Roentgen radiation depends on the voltage across the tube and on the atomic weight of the material of the anticathode. The efficiency increases with the voltage and the atomic weight of the anticathode. A uranium anticathode would be expected to give better efficiency than a tungsten anticathode.

(2) Chemical effects are of great practical value. The most important of these is the effect of the rays on photographic emulsions, reduction of silver chloride and silver bromide. The photographic method of measuring intensity depends on the following facts:

(a) Equal amounts of absorbed energy produce very nearly the same blackening (optical density) on the photographic plate independently of the intensity and the time. If the product of the intensity and the time and hence the absorbed energy is the same, then the optical density is the same. It is, of course, assumed that the kind of emulsion, the thickness of the emulsion, the development factors (concentration, time, temperature, time elapsing between exposure and development) are kept constant.

Since the absorption of the rays depends on the hardness, the photographic method can be used for comparing the intensities of two beams only if the components of the beam are of the same hardness.

Departures from the law given above have been observed. If the factors of the product are widely different then the blackening (optical density) is not rigorously constant. For example, if the intensity and the time are varied in the ratio of 1:5, their product remaining constant, then the blackening is least for the case of low intensity and long exposure time.

(b) As the energy increases, the blackening increases. The blackening is not a simple function of the energy, but the relation between the two quantities can be determined empirically for any given emulsion, developer or hardness of radiation. The behavior is shown graphically in Figure 10.

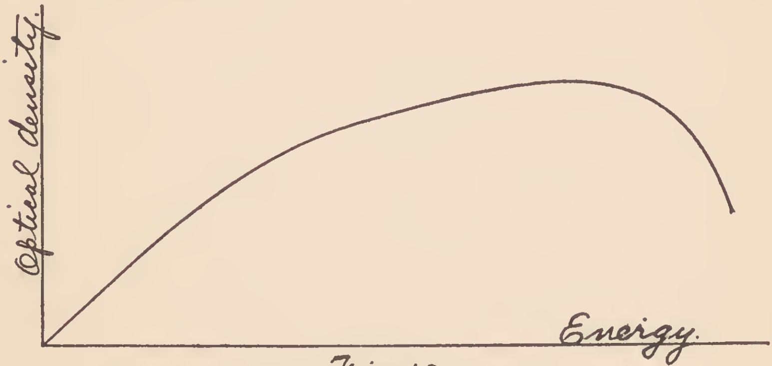


Fig. 10.

Relation Between Optical Density of Photographic Film and Applied Energy.

For small energies the blackening is proportional to the energy, with larger energies it is more nearly proportional to the logarithm of the energy. With very large energies, however, the blackening decreases with increasing energy (photographic reversal).

A lower limiting value, which must be exceeded before any blackening is produced, as is met with in the case of ordinary light, does not appear, according to Glocker, with Roentgen rays.

Corresponding to the phenomena mentioned above there are two possible modes of procedure in comparing intensities by the photographic method.

The first consists in determining the density curve or constructing a density scale. Under identical conditions,

a number of films are exposed with a series of increasing exposure times, for example 0, 2, 5, 10, 30 minutes; 1, 3, 6 hours.

In this way the relation between the blackening (optical density) and the intensity is determined. Unknown intensities can now be estimated by matching them against these films. This is the principle underlying the use of the Kienboeck strips for measuring the energy of the Roentgen rays and estimating the biologic effect. The Kienboeck method consists in exposing bromide paper enclosed in an opaque wrapper, developing for a definite time with a standard developer, and then comparing with a standard scale. The various densities of the scale are designated by numbers which give the absorbed energies in X units. The X unit is arbitrarily defined; according to Kienboeck with soft rays 10 X produce an erythema. However, the effect depends greatly on the hardness of the rays. For this reason as well as the fact that the method involves many sources of error, the results obtained are not very accurate or reliable. For the calibration or the comparison of different Roentgen apparatus the method is entirely unsuitable.

Dessauer has used a modified and more exact method for measuring the distribution of Roentgen intensities within the interior of a rayed medium. To eliminate fluctuations occuring in the Roentgen ray tube the films were placed in a water phantom and all exposed simultaneously. At the same time they were developed by adding a small amount of developer to the water. In this way all sources of error which occur in handling the films are eliminated. A curve giving the optical density as a function of the energy is obtained by exposing a series of films for various lengths of time under identical conditions.

The intensity measurements are relative, the intensity at the surface being taken as the standard of comparison.

This method is very convenient for determining the distribution of intensity when radium rays are used; on account of the constancy of the source in this case, the observations can be made in succession. The results are reliable if the rays have been strongly filtered, since the hardness does not change as the rays penetrate the tissues. When weak or no filtration is used the question arises whether the effects which the beta and gamma radiations produce on the photographic plate are in the same ratio as the effects which they produce in living tissue. However, as will be shown in a later chapter, only a rough proportionality exists between the two. The values, which are obtained by a method of this sort are not very accurate but can serve as a first approximation. The intensity distribution curves of radium are for the most part obtained by this method.

The second method consists in exposing a number of films for various lengths of time and determining by trial the time required to produce the same blackening. Then the intensities, as a first approximation, are in the inverse ratio of the exposure times. This method avoids the use of a density scale.

Many substances change color when exposed to Roentgen radiation; for example, the green color of barium platino cyanide changes to a yellowish brown color. A number of processes of determining Roentgen intensities are based on this property, in particular that of Sabouraud Noiree, Holzknecht, Bordier. Holzknecht has introduced the H unit, which is characterized by the fact that 5H produce an erythema with rays of medium hardness. All these methods, however, are not suffi-

ciently accurate to insure reliable results or enable calibrations.

A method introduced by Freund is based on the liberation of iodine from a chloroform solution of iodine. According to the researches of Glocker, this method is not suitable for accurate measurements. After a certain quantity of energy has been supplied, the reaction is self-supporting and goes on without requiring a further supply of energy, the greater part of the liberated iodine can be the product of this second stage of the reaction.

Of greater practical importance is the change of electrical resistance of selenium under the influence of Roentgen rays. This is primarily a chemical change; when selenium is exposed to radiation it goes over into a modification with a different specific resistance. This reaction depends on the intensity of the radiation. Hence, the change of resistance of a selenium cell or the variation of the electric current through a selenium cell can be used for intensity measurements. The process is by no means instantaneous either during the beginning or after the end of the exposure, so that some precautions must be taken if correct results are to be obtained. It is necessary to wait about a half minute after the exposure has begun for the deflection to become constant before any readings are taken; and the measurement must not be continued for too great a period since the cell may show fatigue. If comparison measurements are to be made, it is very essential that the first reading be checked as a final measurement.

Fuerstenau introduced the selenium cell into Roentgen practice and designed the so-called intensimeter. The latter consists of a selenium cell which is connected by two wires some five meters in length to the auxiliary

apparatus, namely, a battery and a milliammeter. The selenium cell is put in the path of the rays at the point where the intensity is to be measured. The deflection of the instrument indicates the intensity of the radiation in terms of an intensity unit which is derived from an energy unit. According to Fuerstenau an application of 130 F is necessary to produce an erythema with hard rays. Unlike the other chemical methods so far discussed this method does not measure the total energy applied, but measures instead the intensity at any instant. It is only after multiplying by the time factor, that the total energy applied is obtained. The instrument is calibrated in terms of F/min, that is, in terms of the quantity of radiation applied per minute, hence in intensity units.

From the indicated intensity and the required energy, the necessary exposure time can be calculated. This will be illustrated by an example:

Let the intensity be 1 F/min and let 120 F be required. We have accordingly, if the time is represented by X:

$$(1\ \mathrm{F/min}) \times (\mathrm{X\ min}) = 120\ \mathrm{F}.$$

$$\mathrm{X} = 120\ \mathrm{min}.$$

An exposure time of 120 minutes is therefore required.

Various intensimeters show differences in calibration. Even the same instrument slowly changes with time, so that it must be frequently checked against the biologic reaction. Again, the instrument cannot be well used to compare rays of different degrees of hardness since the readings of an intensimeter depend to a high degree on the wave length of the radiation. Its chief application is for the control of operating conditions: it will quickly indicate an incorrect filter thickness and an incorrect focal distance, or some other fault in the technique. Its

great advantage lies in the extreme simplicity of its manipulation, which is as simple as that of an ammeter.

All of the foregoing chemical methods of measurement have a series of disadvantages:

(a) The units used are arbitrarily defined and are not derived from any physical system of units.

(b) Quantitatively, the reactions on which the measurements are based are not proportional to the intensity of the radiation; the relation in any case must be determined empirically.

(c) The reliability, accuracy, and comparability of the methods leaves much to be desired.

(3) We now come to the discussion of the ionization method, a method which overcomes all the above difficulties. In particular:

(a) The ionization method leads to a unit which is based on the fundamental system of physical units, that is the absolute (centimeter-gram-second) system.

(b) The ionization is proportional to the intensity of the radiation.

(c) The ionization method gives very accurate results and can be used to compare Roentgen apparatus and carry out calibrations.

The ionization method depends on the ionizing effect of Roentgen rays on gas molecules. When a beam of rays penetrates a gas, electrons are knocked out of some of the molecules; part of these electrons attach themselves to other molecules; and in this way positively and negatively charged carriers (ions) are formed.

In order to utilize this phenomenon for measurements, two parallel metallic plates are brought into the gas; they are charged one positively, the other negatively by connecting them to a source of E. M. F. (electromo-

tive force), and a current measuring instrument (a galvanometer) is inserted into the circuit as in Figure 11.

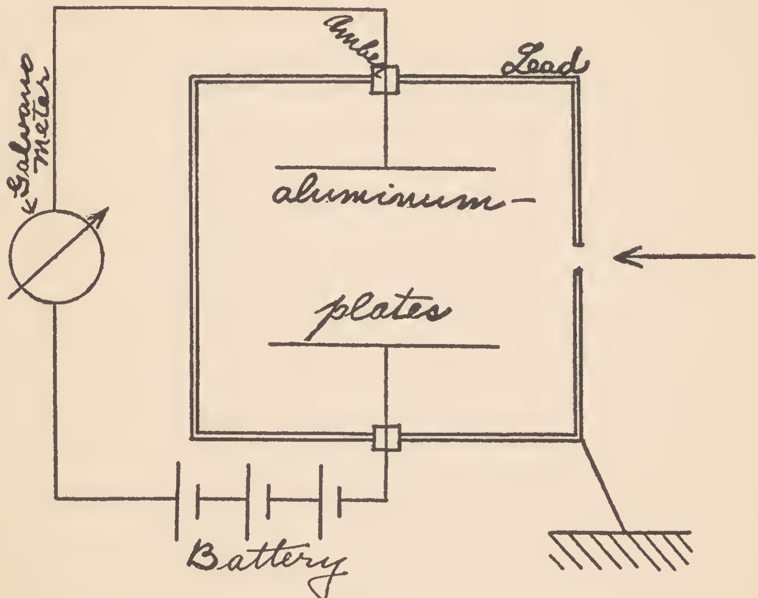


Fig. 11.

Diagram of Ionization Chamber.

If there is no Roentgen radiation, no current flows since the gas consists only of neutral molecules and is not conducting. If, however, a beam of Roentgen rays passes through the gas, the latter is ionized. On account of the attractions and repulsions exerted by the charged plates on the ions, the latter drift to the plates and in this way serve as carriers of electricity. They neutralize part of the charge on the plates; and a current flows from the source of E. M. F. to balance this loss. The galvanometer will therefore show a deflection. If the potential difference between the plates is small, the ions travel with a low velocity and only a few reach the plates and give up

their charge, most of them recombine on the way. If the applied potential difference is increased, the velocity of the ions becomes greater on account of the increased attraction and repulsion. Consequently fewer ions recombine, more of them reach the plates, and serve as electric carriers, hence the current increases. It increases in proportion to the potential difference, and Ohm's law therefore applies also to the conduction of electricity through gases under these conditions.

Of course, if the potential difference is further increased, a point is reached when all the ions formed are utilized to carry the current, then further increase in voltage does not produce an increase in current. This current which is independent of the voltage is called the saturation current. If now the intensity of the radiation is increased, the current again increases, moreover it increases directly as the intensity of the radiation. The saturation current is therefore independent of the applied voltage but varies directly as the intensity of the radia-

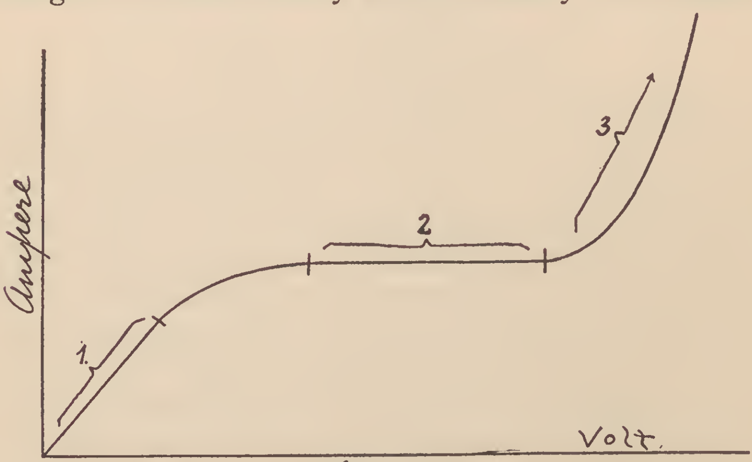


Fig. 12.

Characteristic Curve of Gaseous Conduction.

tion. However, if the voltage is greatly increased, another phenomenon appears: the velocity of the ions becomes so great, that new ions are formed by collision with neutral molecules. In this way myriads of new positive and negative ions are formed and the current rises very rapidly. This phenomenon is called ionization by collision.

Figure 12 shows graphically the variation of the current with the potential difference: (1) is the range in which Ohm's law applies; (2) that in which saturation current is reached, and (3) the region of ionization by collision.

In making ionization measurements care should always be taken to work only with saturation currents. An increase or decrease in voltage should not change the current. By applying this test a possible source of error can be avoided.

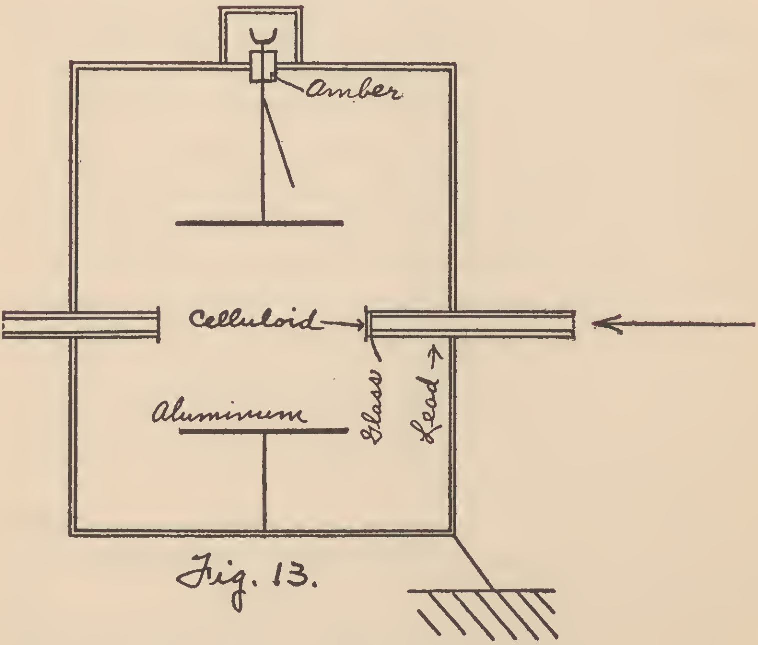
The method of measurement described above makes it possible to measure the intensity of the Roentgen rays in absolute units, that is in electrostatic "e" units. In order to make the unit consistent Duane has proposed the following conditions:

(1) The absorption of the Roentgen rays is to take place in one cubic centimeter of air at standard conditions: 0° C and 760 millimeter pressure.

(2) The measurement must include not only the electrical effect of the primary ions produced in this cubic centimeter, but also the electrical effect of the secondary ions which are produced in the surrounding region. The second condition is necessary because of the fact that high velocity ions, chiefly electrons, are produced in the volume subjected to radiation and these ionize the surrounding air. Surfaces, metallic surfaces especially,

must be so far removed that they are not reached by primary ions, that is to say, they must lie outside of the range of the primary ions. Otherwise ions strike the surface before they have transformed their entire energy into secondary ions. If this takes place, the measured intensity is too low.

These conditions are best satisfied by the following apparatus: see Figure 13.



Electroscope for "e" Measurement.

The rays enter a large lead lined chamber through a small lead tube which carries thick walled brass diaphragms at the ends and leave through a similar tube lying in the prolongation of the first. At the inner end of the first tube a glass plate, the absorption coefficient of which is known, stops the secondary radiation from the

lead and the brass, while a celluloid disc absorbs the secondary radiation coming from the glass. The second tube is also closed at the inner end by a celluloid disc. By the distance between the two celluloid discs and the cross section of the beam the volume subjected to radiation is definitely determined; the cross section is measured photographically at a number of points. A larger volume than one cubic centimeter is subjected to radiation for the following reason: The two celluloid discs introduce an inaccuracy; at these surfaces the electrons are stopped and do not transform their full energy into secondary ions but excite surface radiation. The greater the length of the cylinder of air subjected to radiation the more nearly negligible will be this error and the more accurately it can be corrected for. The effect produced per cubic centimeter is obtained by dividing by the volume

The electrodes consist of a pair of aluminum plates, which are mounted parallel and at a distance of 8 or 10 centimeters from the axis of the beam.

A measurement of the current gives the number of electrosatic units transported across per second, from which the number of electrostatic units produced per second per cubic centimeter irradiated can be obtained. Since we are dealing with extremely small currents, it is simpler to measure the number of electrostatic units produced during a given time by measuring the potential drop of a charged electroscope during the same time.

The electroscope connected to one of the plates is charged and allowed to discharge between two fixed divisions. Each division corresponds to a definite voltage. If the electrical capacity of the system is known, the changes in electrical quantity can be calculated in electrostatic units. By means of a stop watch the time during

which the discharge took place can be determined. During the observed time—t seconds—a number of electrostatic units given by

$$\frac{V_{\text{volts}} \times C_{\text{capacity in cm}}}{300}$$

are discharged. If this corresponds to 10 cubic centimeters of air, then 1 cubic centimeter would discharge 1/10 of this amount; in one second the discharge is

$$\frac{V \times C}{300 \times 10 \times t}$$

electrostatic units.

The electrostatic unit mentioned above is the unit of electrical quantity in the absolute system of physical units, that is, the so-called C. G. S. (centimeter-gram-second) system. Hence the measurement carried out above measures the effect of Roentgen rays in absolute units.

To summarize:

The electrostatic effect of Roentgen rays is measured by the saturation current produced per cubic centimeter of air at standard conditions in a chamber large enough to insure the full effect of the secondary ions. The number of electrostatic units of charge produced per second per cubic centimeter is a measure of the intensity of the Roentgen radiation.

From the intensity measurement in electrostatic units the total quantity of energy which the patient receives can be determined. The intensity need only be multiplied by the time of exposure. However, attention must be called to a possible source of error. The intensity is measured in accordance with the definition in a volume of air surrounded by air. In determining the intensity to which the patient is subjected the intensity is measured within a scattering medium or at the boundary

between a scattering medium and the air. We have already seen that at this point the secondary scattered radiation back from the interior adds to the primary radiation and in extreme cases may be as high as 50 per cent of the latter.

For the sake of physical exactness it must be emphasized that the method of measuring intensity in electrostatic units, as well as any one of the other methods used in practice, does not measure the transmitted energy but measures instead the fraction absorbed per cubic centimeter. Hence we are not measuring intensity in the exact physical sense. Strictly speaking, the intensity when multiplied by the exposure time ought to give the total energy. The intensity as measured in practice, however, when multiplied by the exposure time, gives the absorbed energy, that is, the dose.

The true intensity (in the physical sense) is measured with long chambers filled with gases of high molecular weight; it can also be calculated from the absorbed energy when the hardness is known.

The results of careful measurements made with the ionization method will now be given in detail.

The intensity obtained with a regular transformer under standard conditions, that is

200 K V,
5 M A,
1 mm of copper plus 1 mm of aluminum,
50 cm focus skin distance,

is approximately 0.25 e/sec or 15.0 e/min measured without a scattering medium.

When large ports of entry are used, this means an intensity at the surface of the skin of 0.37 e/sec or 22 e/min.

According to measurements made by Duane and the author approximately 1800 e result in a mild erythema. With the above conditions therefore $\frac{1800}{22} = 82$ min or 410 milliampere minutes are necessary for an erythema. Some transformers (single wave rectification, poorly adjusted rectifier, transformer of high magnetic leakage) deliver only 0.14 e/sec or 8.4 e/min; at the surface of the skin therefore 2.1 e/sec or 12.6 e/min. A mild erythema is therefore given in $\frac{1800}{12.6} = 143$ minutes or with 715 milliampere minutes.

Approximately the following energy values are necessary to produce the various reactions stated.

1500 "e" first indication (in some cases) of an erythema.

1800 "e" mild erythema in most cases.

2100 "e" definite erythema.

2700 "e" first degree burn.

3700 "e" second degree burn.

These values apply to heavy filtration; for light filtration or no filtration, the values given above are too high.

The large ionization chamber described above can only be used for scientific measurements in an institute; the manipulation is difficult and complicated. For practical work two kinds of instruments are on the market, namely, the electroscope and iontoquantimeter.

The electroscope is a lead shielded chamber, which contains the indicating instrument and the air to be ionized. One form is shown in Figure 14 on page 75. It represents the Bachem and Ziehn calibrated electroscope.

The instrument is light, easily manipulated, and can be taken apart for shipment. Two parallel aluminum

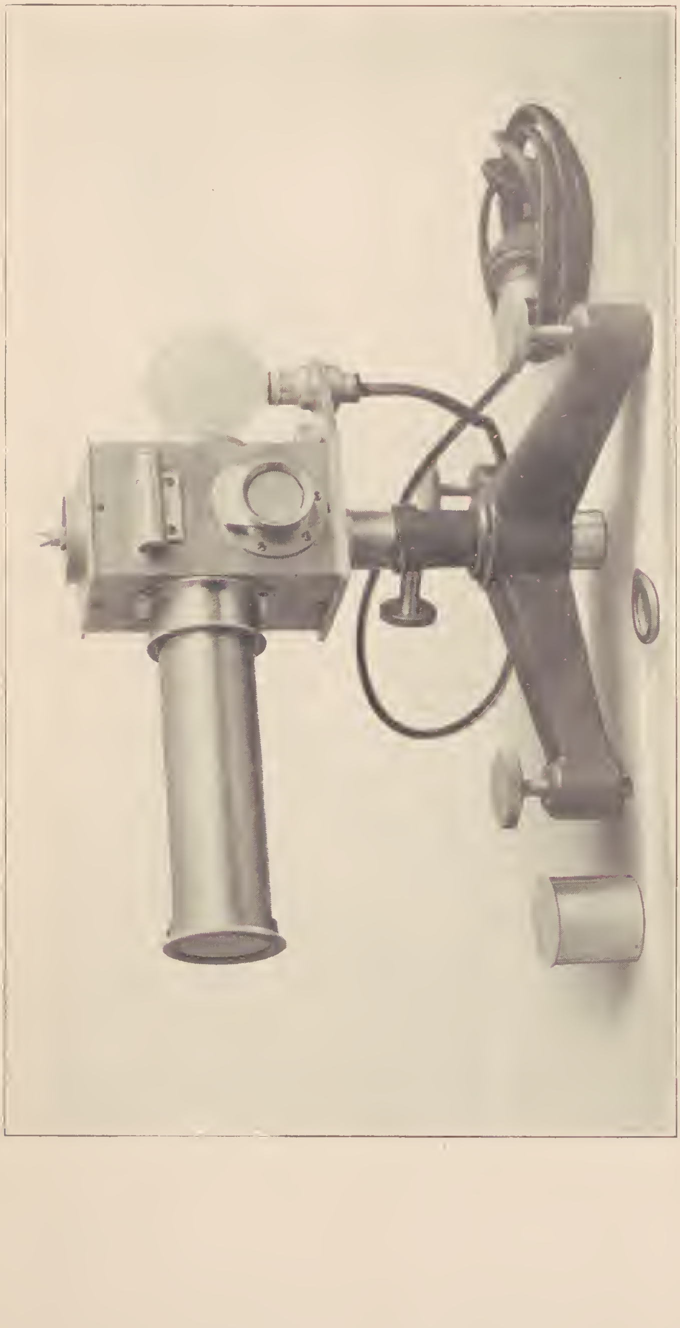


Fig. 14.
Bachem Ziehn Electroscope.

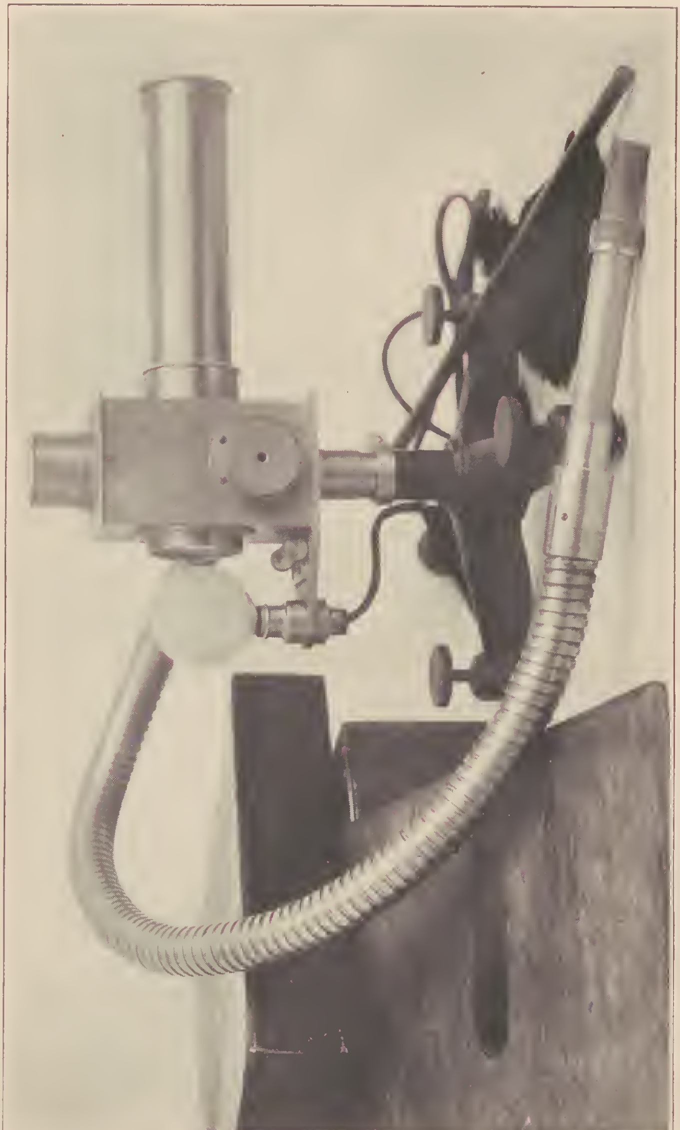


Fig. 15.
Bachem Ziehn Iontoquantimeter.

plates are fixed in a horizontal position, the lower one being connected to the case, the upper one well insulated from it. The upper plate carries a pivoted, partially balanced, aluminum pointer which is made from a piece of rolled aluminum wire. By means of a small electric light bulb and a lens a sharp image of the shadow cast by the pointer is projected on a ground glass screen which carries a graduated scale. The time of discharge between two fixed divisions is measured with a stop watch. The electroscope is charged by removing a lead cap and touching a metal knob with an electrified hard rubber rod. The pointer comes to rest almost instantly without oscillating, both at charge and discharge. Undesirable discharge does not take place, neither is there any stray radiation to be corrected for. By means of two levels the instrument can be accurately adjusted, so that the same conditions can always be duplicated. The rays enter the chamber through the window, in front of which is mounted a holder to accommodate various filters. At the opposite side is a lead glass window through which the anticathode can be sighted for adjustment. However, such an exact adjustment is not necessary, it is sufficient to turn the window in the general direction of the anticathode. The relation between the time of discharge and the erythema exposure time for the various wave lengths is given for each instrument so that by means of a stop watch measurement and a wave length measurement (to be discussed later) the erythema time can very accurately be determined.

The instrument is controlled by means of radium. This is done by placing a known quantity of radium element, say at 5 or 10 mg radium needle, at a chosen point and observing the time of discharge. This is done for two reasons:

(1) The time of discharge of the instrument depends on the barometric pressure, temperature, and humidity. For all practical purposes the barometric pressure is of significance only when the measurements are carried out at different sea levels. A measurement of the discharge time with radium makes it possible to determine very easily the sense and magnitude of the error introduced by changes in air pressure. If, for example, the instrument is calibrated in Chicago under standard conditions and a discharge time of 20 seconds is observed with 10 milligrams of radium; then if later a measurement is made in Denver for the purpose of calibrating a Roentgen installation there, it is found that the same quantity of radium causes discharge time of 24 seconds. This means that due to the lower atmospheric pressure and consequent smaller absorption of radiation in the instrument every discharge appears too large in the ratio of 24:20. On this account every observed value must be decreased in the ratio of 20:24 before the erythema time can be determined. If in Chicago a discharge time of 30 seconds corresponds to an erythema exposure time of 4×30 or 120 minutes (determined by experiment), then in Denver an observed discharge time of 42 seconds would not signify an exposure time of 4×42 or 168 minutes, but the observed value of 42 seconds would have to be corrected by the factor 20:24, and the corrected value, namely 35 seconds, used as the basis of calculations. This would give 4×35 or 140 minutes as the correct erythema time. The factor 4 which is based on physical and biological observations gives the relation between the discharge time in seconds and the erythema time in minutes, and may be called the physical-biological factor of the instrument. It is different for each instru-

ment and must be determined by calibration for any given one. It also varies with the hardness of the radiation.

(2) The test measurement with radium makes it possible to keep a continual check on the instrument. This increases the certainty of a measurement and is especially valuable when repairs are made. If for example the glass scale should accidentally be broken or a new aluminum leaf should be inserted, without a radium control a new calibration would be necessary. In most of these cases the use of the radium control obviates this. If the check with radium gives a value of 5 per cent higher than was obtained previously, then all readings are 5 per cent too high and must be decreased by 5 per cent.

The iontoquantimeter differs from the electroscope in that a smaller chamber is used, Figure 15 on page 76. A small ionization chamber has a series of advantages over a large one, namely:

(1) It can more easily be placed at points where the intensity is to be measured under the exact conditions of the treatment. For example, it can be placed on the skin of the patient or inserted into cavities of the body. It can also be used at the surface or at various depths of a water phantom and can therefore serve as a means of investigating the intensity distribution within the tissues.

(2) A small chamber can be so constructed, as Friedrich has shown, that the physical-biological factor, that is, the ratio between the erythema exposure time in minutes and the discharge time in seconds becomes practically independent of the hardness of the radiation. This is of great importance, as the method of comparing rays of different wave lengths is greatly simplified.

However, the small chamber has the disadvantage that the indicating instrument can no longer be contained within the chamber but must be placed outside of it. This involves three difficulties:

(1) Leakage;
(2) Stray radiation;
(3) Dielectric absorption.

Leakage is caused by poor insulation and takes place spontaneously independent of the Roentgen radiation. Stray radiation is the radiation which penetrates the lead shield of the electrometer case and produces ionization within. During an actual measurement both of these disturbing factors act simultaneously. Their combined effect is known as undesirable discharge and must be determined. A cap with lead walls from three to five millimeters thick, slightly longer than the chamber, is placed over the latter and the discharge time noted, all conditions: voltage, milliamperage, distance, position of the chamber, etc., being the same as those used in the measurement. Let this observed time be t_u, it may be 300, 1000 or more seconds; if the value is extremely large an exact measurement is not necessary. The time may be estimated by observing the time taken to pass over a small scale division.

The correction is made in accordance with the following considerations:

The observed value is always lower than the correct value, on account of the effect of leakage and stray radiation. Hence an additive correction is necessary. It is made as follows:

Let the discharge time noted with the ionization chamber at the point where the intensity is to be measured be designated by t_m and let t_m be equal to 30

seconds. Let, in addition, the discharge time noted when the ionization chamber is covered with the lead cap be designated by t_u and let t_u equal 300 seconds. To obtain the true discharge time the product of t_u and t_m is divided by their difference. We have accordingly

$$\frac{300 \times 30}{300 - 30} = 33.3 \text{ seconds.}$$

The true discharge time, which would be obtained if there were no undesirable discharge, is therefore

$$t_c = 33.3 \text{ seconds.}$$

The general formula for the true discharge time t_c is

$$t_c = \frac{t_u \times t_m}{t_u - t_m}.$$

Another example to illustrate the application of this formula is the following:

Let the value of the physical-biological factor obtained by calibrating a particular instrument be equal to 5. This means that the true discharge time in seconds must be multiplied by 5 in order to obtain the erythema time in minutes. Let the normal discharge time with the chamber at the surface of a water phantom be 32 seconds and the discharge time with lead cap over the chamber be 250 seconds. The corrected time, according to the formula, is

$$t_c = \frac{t_u \times t_m}{t_u - t_m} = \frac{250 \times 32}{250 - 32} = \frac{8000}{218} = 36.5 \text{ seconds.}$$

The erythema time in minutes is obtained from the true discharge time in second by multiplying by 5:

$$36.5 \times 5 = 182.5.$$

Hence an exposure of 180 minutes or three hours results in an erythema in this case.

It is readily seen that the approximate magnitude of the correction depends on the ratio of the two observed discharge times t_u and t_m.

If this ratio is 10 : 1 the correction is 11%.

If the ratio $t_u/t_m = 100 : 1$ the correction is only 1% and can be neglected.

If the ratio $t_u/t_m = 3 : 1$ the correction would be 50%. However in this case the result is no longer accurate.

The relation can be shown by a curve, which obviates timesome calculations (Fig. 16).

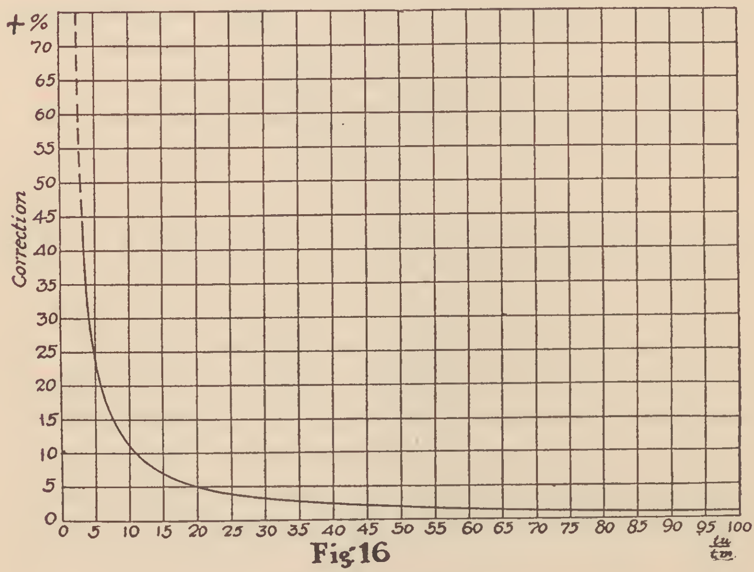


Fig. 16

Correction Curve.

The value of the ratio t_u/t_m is determined and located on the horizontal axis of the graph, the height of the curve at a given point gives directly the magnitude of the correction. This correction is additive.

As a result of dielectric absorption the discharge time depends somewhat on the manner of charging the electroscope. The measured time at first is usually too low because the dielectric absorbs part of the charge. On the other hand, if the dielectric has been overcharged, a part

of the charge creeps out during the measurement and makes the discharge time too high. The iontoquantimeter should therefore be charged about fifteen minutes before the measurements are begun; and the first readings discarded until they become fairly consistent under the same conditions. During the measurements the iontoquantimeter should always be charged to the same scale division.

The measurement of hardness with the iontoquantimeter will be discussed later.

A reliable iontoquantimeter calibrated in terms of erythema exposure times can be obtained from the author.

Duane constructed an iontoquantimeter consisting of a somewhat larger chamber and a galvanometer sensitive enough to read the current furnished by a battery. This instrument, therefore, like the intensimeter, indicates the intensity at any instant.

4. Biologic Scales and Methods of Measurement.

Besides the physical units and methods of measurement, biologic reactions are also used to define intensities and to carry out measurements. Such biologic reactions have an especial advantage over physical methods in that a closer relation exists between them and the reaction it is desired to produce in human tissue. From the reaction of mouse cancers to various intensities of Roentgen radiation the behavior of a tumor in the body of a man can better be predicted than from any physical experiments; from the reaction of sprouting beans to rays of various wave lengths better conclusions can be drawn with regard to the general effect of rays of various wave lengths on body tissue than from purely physical measurements.

On the other hand, these methods have the disadvantage that they are less exact than physical measurements and that biologic scales are purely arbitrary and subjective. These measurements also require a considerable period of time since the biologic effect becomes evident only after some days or weeks. The most important biologic scale is the gradation of the skin reaction produced by Roentgen and radium rays. No other biologic reaction can be observed so clearly or has been observed so frequently as this one. During the entire period of development of deep therapy the skin reaction was the measure of correct dosage. During recent years various skin reactions have served as units in terms of which the reaction of other normal and diseased tissues were compared. To this class belong:

The unit skin dose of Seitz and Wintz.

The erythema dose of Kroenig and Friedrich.

The erythema dose of Schmitz.

Seitz and Wintz define a unit skin dose as the quantity of radiation which, eight days after exposure, produces a slight reddening and fourteen days after exposure, a slight browning of the skin. This dose is now used almost exclusively for the comparison of various treatment techniques. We shall come back to it in the chapter on Practical Dosage.

From the statements made by Kroenig and Friedrich their erythema dose appears to be somewhat stronger than that of Seitz and Wintz, although the expression "first degree erythema" does not fix the limits very closely. According to measurements made by the author, differences as great as 20 to 30 per cent exist between the two doses. The 100 per cent erythema of Schmitz corresponds approximately to that of Friedrich.

The assertion of Schmitz that his erythema dose is double the erythema dose of Friedrich and three times the unit skin dose of Seitz and Wintz is not in accordance with the facts. It is contradicted by both biological observations and physical measurements. Since Schimtz' assertion that he gives a dose as high as three times the unit skin dose of Seitz and Wintz may lead the beginner to give treatments resulting in serious burns, the conditions which actually obtain should be mentioned at this point.

In spite of the many observations which have been made on skin reactions, the statements made by various investigators are widely contradictory with regard to the consistency of the appearance of the erythema. Some authors assert that the skin reacts within narrow limits to the same energies; others mention especially strong reactions noticed with some individual (idiosyncrasies) and total indifference with others. The author is of the opinion that in his practice of physical dosage closely compared with biological observation he has found no large deviations from the mean. He has verified that children and blondes react the stronger as a rule. For this reason the dose given to children should be less than that given to adults; infants and children less than five years old should be given only half of the adult dose; older children may be given three-fourths of this dose.

Kroenig and Friedrich, who carried out the most accurate physical dosations and collected a large amount of experimental data, mention several cases of extraordinary low susceptibility; they have given to especially cachectic patients almost double the ordinary skin dose and produced only a light browning of the skin.

Gauss and Lembke have shown that in cases of

so-called Tizian-teint so high a susceptibility exists that the skin reacts to half the ordinary dose. However, such cases of abnormal susceptibility are comparatively rare and do not prevent the definition of a skin dose for normal skin.

Holzknecht and Altman distinguish the following degrees:

(1) First degree; latent period three weeks.

The reaction proceeds without visible inflammation and is characterized by epilation, resorption of pathological tissue and frequently the appearance of a pigmentation. End result: restitutio ad integrum.

(2) Second degree: latent period two weeks.

The reaction is characterized by epilation, erythema, swelling and subsequent scaling of the skin. Itching and burning occurs. End result in general restitutio ad integrum. However, there are cases in which after a long time following a single reaction of the second degree, there has occured atrophy and formation of telangiectasies; even without being preceded by a visible reaction, telangiectasies with or without simultaneous mild atrophy have been observed.

(3) Third degree: latent period about one week.

To the symptoms of the second degree are added the formation of blisters, and weeping excoriations. The erythema takes on a dull blue red color; the subjective complaints are frequently very pronounced. Healing can occur without permanent change of the skin, frequently, however, skin atrophy results together with destruction of sudoriferous and sebaceous glands and hair follicles, and telangiectasies, which may appear soon but usually appear after a period of several months. Occasionally even after a period of some years necrosis occurs.

(4) Fourth degree: latent period a few days.

To the symptoms of the third degree deep ulcerations are added; subjectively extremely pain. Healing takes place after months or years often with the help of transplantation and with atrophy of the skin, telangiectasies, a permanent loss of hair and of sudoriferous and sebaceous glands. At times belated necroses occur after some years.

For hard rays Schmitz distinguishes similar gradations. The four degrees correspond respectively to his

(1) Epilation dose.
(2) Erythema dose.
(3) Estal skin dose.
(4) Lethal skin dose.

According to measurements made by the author, the following energies are required to produce various reactions as noted:

(1) Epilation dose, 70 per cent, 1500 e.
(2) Erythema dose, 100 per cent, 2100 e.
(3) Estal skin dose, 130 per cent, 2700 e.
(4) Lethal skin dose, 175 per cent, 3700 e.

The energies required for various therapeutic purposes will be given in the last chapter.

In this place a few details may be added regarding the relation between the biologic reaction and the quantity of radiation applied. The statement has often been made that the biologic reaction is proportional to the energy of the radiation. This statement is meaningless since we have no scale of measurement for the totality of biologic effects and therefore cannot give numerical values. It is true that a few reactions such as the decrease in red or white blood corpuscles can be expressed numerically. So far, however, even in these cases the data available is

not sufficient to determine the exact nature of the function involved. The curves resemble exponentials, but deviate considerably from this form.

The best investigations along this line are the experiments of Wood and his co-workers on mouse tumors. One of the curves given by Wood is shown in Figure 17.

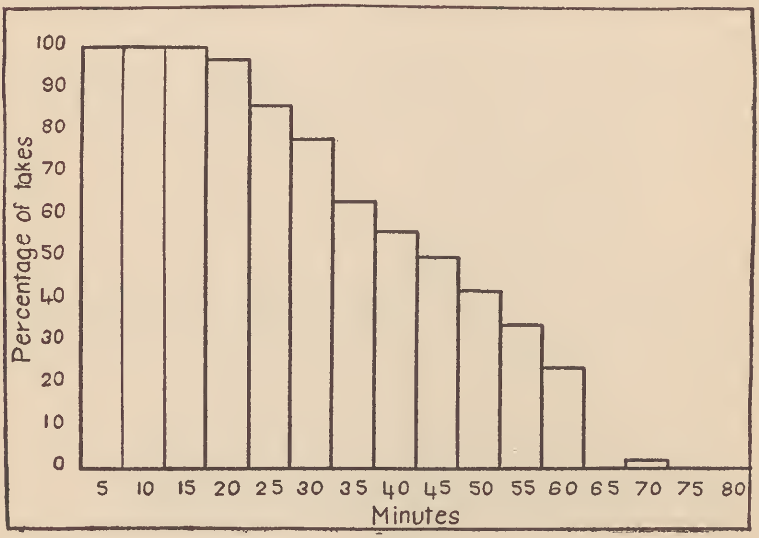


Fig. 17.

Percentage of Takes of Tumors Obtained with Various Exposure Times. (Wood.)

With a radiation time up to 15 minutes 100 per cent of the tumors take. Beginning at 20 minutes the percentage of "takes" begins to decrease, slowly at first and then more rapidly. The end run of the curve is somewhat uncertain. The curves show very plainly, however, that we cannot speak of proportionality, moreover, it suggests that there may be a stimulating effect; proof of this could be obtained by the method used if conditions

could be so chosen that with unexposed tumors the percentage of takes were less than 100 per cent.

Another question frequently raised is whether the same applied energy produces the same biologic effect independent of the separate factors, intensity and time. Very exact biological and physical measurements along this line were carried out by Kroenig and Friedrich. They found that as long as the variation was small, the values of the separate factors were not significant. For example, it is immaterial for most purposes whether a given quantity of energy with a centain intensity is applied in 1 hour or with ⅓ the intensity in 3 hours.

If, however, the same energy were applied in one case in ½ hour and in the second case in 5 hours, the biologic reactions would be different. A weaker reaction would be noted in the second case. The difference becomes appreciable only when the intensity and the time are varied in the ratio of 1:5. The results are similar in the case of a treatment series which is given during one day or during the course of one or more weeks. The effect on cancer tissue is greater when the treatment is carried out in a short time; however the undesirable effects, nausea, changes in blood, are also greater. By distributing the raying over a week the last mentioned effects can be greatly mitigated while the action on the cancer cells and ovaries is not appreciably weakened. According to Kroenig and Friedrich the treatment must be distributed over 10 to 13 days before the reaction is appreciably diminished. The observations indicate that the raying should not be condensed into too short a time; the author's experience has been that it is best to distribute a cancer treatment with four fields over 5 or 6 days; then

the full action on the cancer is assured while the undesired effects are greatly mitigated.

In the repetition of a skin treatment the rule may be applied that the skin can stand more if the treatment is distributed over the course of a week than if the raying is given in one sitting. In the repetition of a series treatment the rule may be applied that with a weak erythema the skin can withstand the same applied energy at intervals of 6 to 8 weeks up to 3 to 4 applications. Data of this sort for various organs would be invaluable in the treatment of various glandular organs (suprarenals, pancreas); since it would be a guide in ascertaining a harmless but effective treatment.

Similar investigations have been carried out on the action of radium preparations. Seitz and Wintz used three different preparations with approximately 150, 100, 50 milligrams of radium element, they determined the time required to produce the same reaction on cancer tissue at a depth of several centimeters with the same conditions of filtration and distance.

The following table gives the results:

Milligram radium element	Hours	Milligram hours
150	20	3000
100	33	3300
50	72	3600

With a smaller number of milligrams the required exposure time is greater then would correspond to the same applied energy.

With a decreasing number of milligrams and a corresponding increase in the exposure time the milligram hours increase; that is to say the smaller the time con-

centration of the energy (intensity) the greater is the amount of energy which must be supplied. This is similar to the results obtained with Roentgen rays. [The exact distance and times were not available to the author; the ratios of the milligram hours are correct.]

The observations of Wood and Prime do not agree with these results. Mouse tumors were rayed with preparations of various strengths for various lengths of time and the conditions which represent the minimum lethal dose ascertained. With strongly filtered rays (1.2 millimeters brass plus 5 millimeters paper) the following values were obtained.

Milligrams	Hours	Milligram hours
100	7	700
83	7.2	600
30	15	450
17	20	340
10	36	360

For lightly filtered rays the following values were found:

Milligrams	Hours	Milligram hours
100	1	100
83	1.1	91
30	1.7	51
20	2.5	50
17	3.0	51
10	5	50

Both tables indicate constant milligram hour values for the case of weak preparations. For very strong preparations and short exposure times the number of

milligram hours shows a tremendous increase. It looks as though a strong energy concentration produces a considerably smaller biologic effect, just as a prolonged dose results in a weaker reaction. However, these phenomena are not yet definitely established. At least they require verification.

CHAPTER II

Definition and Measurement of Quality.

Equally as important, both biologically and physically, as the intensity of the radiation is its hardness. Roentgen rays of equal intensity can differ widely in other respects, in wave length, in absorption coefficient or reciprocally expressed, in penetration or hardness, in scattering coefficient, and in biological effect. These properties are grouped together under the general term *quality*. The quality can be measured in many ways corresponding to the various properties mentioned. However, the wave length of the radiation is the most important of these various properties for several reasons:

According to the wave length, the various radium and Roentgen rays can be placed in the well known series of electromagnetic rays which include visible light, ultra violet rays, heat rays, wireless waves, etc.

The concept of wave length is univalent, simpler and more comprehensive than other concepts of quality: penetration, absorption, scattering, etc.

The wave length measurement is more accurate than any other physical measurement of quality.

The various physical laws involving quality can be formulated simplest in terms of the wave length as the independent variable.

For this reason we shall first take up the wave length and the spectrum of Roentgen radiation and the γ radiation of radium.

§1. Wave length and spectrum of X rays and of γ rays.

Every wave motion can be defined in quality by its wave length. The wave length is the distance between the homologous points in two adjacent waves; for example, the distance from the peak of one wave to the peak of the next. This distance is so minute in the case of light rays, Roentgen rays, or radium rays, that it is measured in terms of the so-called Angstroem unit, which is one ten-millionth of a millimeter or 1/100,000,000 centimeters. In physical notation this is written

$$1 \text{ A U} = 10^{-8} \text{ cm.}$$

The table on page 95 gives the order of magnitude for the various types of radiation in the scale of wave lengths.

The table shows that the shortest ultra-violet rays and the longest Roentgen rays overlap. Within a certain range the same radiation can therefore be produced in optics or by means of the Roentgen ray tubes. It is also seen that the hardest Roentgen rays and the softest radium rays overlap. Rays alike in every respect can therefore be produced by two different sources in this border zone. The only gap in this system of wave lengths exists between the electric waves and the heat waves; up to the present time no rays have been produced or measured in the region from ⅓ millimeter to 1 millimeter.

All these rays have the following physical properties:

(1) Velocity: they travel with the same velocity: 300,000 kilometers per second;

(2) Deflection by electric and magnetic fields: they are not deflected by electric or magnetic fields;

(3) Reflection: they are reflected: Electric waves by every conducting surface; light waves by plane surfaces with more or less diffusion. Roentgen and radium

Radiation	Wave Length	
Electric waves	10 kilometers to 1 millimeter	wireless telegraphy, diathermy
Infra red or heat waves	0.3 millimeters to 0.00077 millimeters = 7700 A U	longest mercury vapor radiation
Visible light	7700 A U to 4000 A U	red violet
Ultraviolet rays	4000 A U 3000 A U	near ultraviolet limit of sun's spectrum
	1800 A U	far ultraviolet, bactericidal
	200 A U	shortest observed ultraviolet radiation (Millikan)
X rays	725 A U	longest known Roentgen radiation (1923, Dember)
	about 5 about 0.3 } A U	radiation used for diagnostic purposes.
	about 0.3 about 0.06 } A U	radiation used in deep therapy
	0.058 A U	hardest X rays, Dessauer and Back (1919)
Radium rays	0.1 A U	soft γ rays
	about 0.025 A U	hard γ rays estimated from observations by Rutherford, Andrade, Compton.
	0.01 A U	limit not definitely known

rays are always diffused because of the fact that every surface is irregular in comparison with their minute wave length.

(4) Refraction: they are refracted:

Electric waves by large dielectric prisms;

Light waves by glass or water prisms;

Roentgen rays and radium rays by irregular scattering;

(5) Diffraction: they are diffracted: Electric waves by parallel wires;

Light waves by so-called gratings;

Roentgen rays and radium rays by crystals, that is by space gratings or lattices;

(6) Polarization: observed with all types of rays;

(7) Absorption: they are transformed into other forms of energy manifested by heating, ionization, chemical effects, biologic reactions, etc. On account of their longer wave length wireless waves and light waves produce a stronger effect on the molecule as a whole than on the atom and electron; hence they produce heating effects (molecular motion) rather than ionization (splitting up of molecules and chemical effects, atomic rearrangement). The Roentgen and radium rays, on the other hand, have a stronger effect on the interior of the atom and the atomic structure than on the molecule as a whole; hence their primary effect is one of dissociation of the molecule and the atom and only their indirect effect can produce molecular motion, that is heating.

On account of their different physical behavior an important biological difference also exists between rays of different wave length. This subject will be further discussed later.

If a beam of Roentgen rays consists of radiation of a single wave length it is said to be homogeneous. If it

consists of components of different wave lengths it is said to be heterogeneous. Actually, there is no strictly homogeneous radiation; even the most sharply defined spectral line has a finite width, that is to say it consists of rays of several wave lengths. The fact that a beam of rays is a mixture of rays of various wave lengths is best shown by photographing its spectrum. This is done with a Roentgen ray spectrometer. This instrument is based on the reflection of Roentgen rays by crystals. If homogeneous Roentgen radiation is allowed to fall on the surface of a crystal at various angles, it is observed that reflection takes place only with certain definite angles between the direction of the beam and the plane of the crystal surface. This angle depends on the crystal, in particular on the distance between atomic planes of the crystal and on the wave length of the radiation used. Furthermore the reflection takes place according to the well known law which states that the angle of incidence equals the angle of reflection. For example, a beam of rays of wave length 0.2 A U is reflected only at the following angles provided, of course, it strikes the surface at the same angles.

$$\alpha_1 = 2° \ 2'$$
$$\alpha_2 = 4° \ 5'$$
$$\alpha_3 = 6° \ 8'$$
$$\alpha_4 = 8° \ 10' \text{ etc.}$$

No reflection occurs at any intermediate angle. In the language of the physicist the intensity is destroyed by interference at intermediate angles. A ray of $\lambda = 0.18$ A U can only be reflected at the angles:

$$\beta_1 = 1° \ 50'$$
$$\beta_2 = 3° \ 40'$$
$$\beta_3 = 5° \ 30'$$
$$\beta_4 = 7° \ 19' \text{ etc.}$$

If in a beam both the wave length $\lambda = 0.20$ A U and $\lambda = 0.18$ A U are present then they will emerge from the crystal at two definite angles, one of which is somewhat greater than 2° and the other somewhat less.

Hence in the general direction of 2° a spectrum will appear, which will consist of two separate beams of different wave lengths.

A similar spectrum will appear at 4°, at 6°, at 8°. These, however, will be broader than the first. The widths will be:

$$\alpha_1 - \beta_1 = 2^\circ\ 2' - 1^\circ\ 50' = 12'$$
$$\alpha_2 - \beta_2 = 4^\circ\ 5' - 3^\circ\ 40' = 25'$$
$$\alpha_3 - \beta_3 = 6^\circ\ 8' - 5^\circ\ 30' = 38'$$
$$\alpha_4 - \beta_4 = 8^\circ\ 10' - 7^\circ\ 19' = 51'$$

It is seen that they vary as 1:2:3:4. The various spectra are designated as spectra of the first order, second order, third order, etc. The spectrum of the first order is the narrowest: the higher orders become continually broader, the dispersion in higher orders is therefore greater and they are not so sharply defined; furthermore, their intensity is a great deal lower.

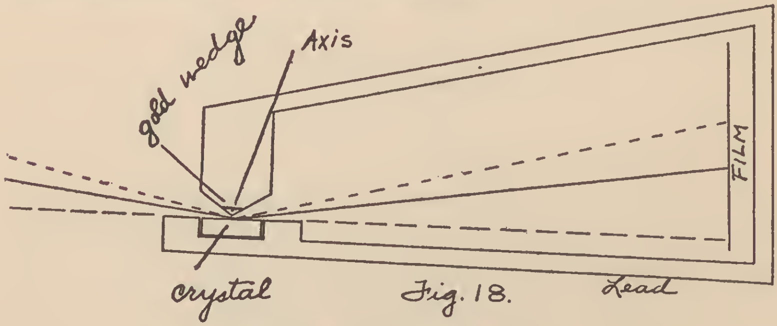


Diagram of Spectrometer.

For the production of a spectrum a spectrometer is used, Fig. 18. The spectrometer consists of a box

shielded against stray radiation by heavy lead walls; the rays enter through a narrow slit between the crystal surface and a gold wedge carried by a lead block. The reflected rays strike a photographic film. The width of the slip between the crystal and the knife edge is adjustable; sharp spectra can only be obtained with a narrow slit. The entire box can be rotated about an axis coinciding with that of the slit. A device driven by clock work moves the entire box with uniform velocity up and down between two fixed points. In this way the Roentgen ray beam is made to strike the crystal surface at all angles; it is reflected at equal angles to the film. In the region of grazing incidence the rays strike the film directly and produce a heavy blackening—the so-called point of "direct ray." This point coincides with the zero point of the angular scale if the crystal has been correctly adjusted.

The spectrum discussed above has the appearance shown in Figure 19.

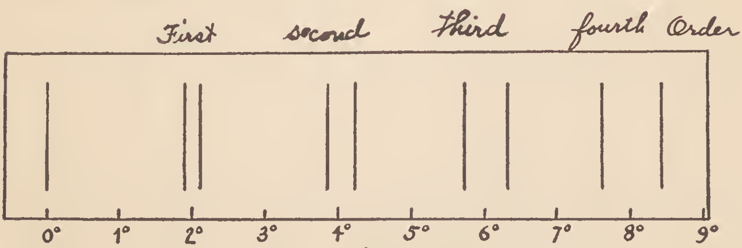


Fig. 19.

Diagram of a Spectrum.

In general, however, a spectrum does not consist of only two wave lengths; it is much more complex. Figure 20 shows the spectrum of a heavily filtered radiation of Coolidge tube with tungsten anticathode. The blacken-

ing of the film depends on the amount of absorbed energy. The latter depends in turn primarily on the hardness of the radiation. The point of the direct ray is an exception—the blackening here is produced by rays of all wave lengths present in the beam.

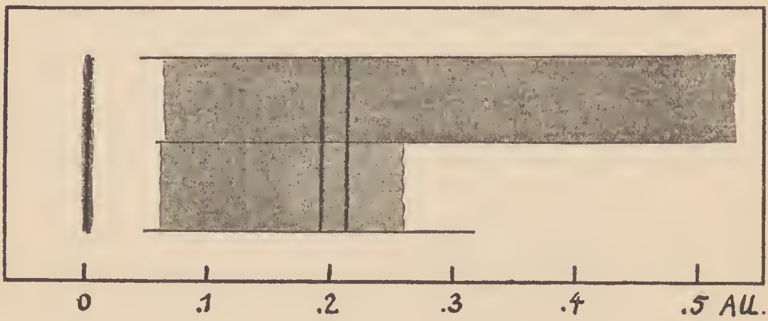


Fig. 20.

Unfiltered and Filtered Spectrum of a Tungsten Antikathode (200 K V, 1 M M Cu + 1 M M Al.).

This spectrum shows that no wave lengths between 0 and 0.06 A U are present. Rays of low intensity first make their appearance at 0.06 A U. The intensity increases continuously and reaches a rather flat maximum at 15 A U. Near 0.18 and 0.20 A U there are two sharp maxima, which from their appearance are called spectral lines. The intensity then gradually decreases; the lower limit, however, cannot be exactly determined because the second order spectrum begins at 0.12 A U and overlaps that of the first order.

The figure shows that the Roentgen spectrum can be thought of as composed of two different types of spectra: a continuous spectrum and a discontinuous one.

The continuous spectrum in our particular case includes all wave lengths in the range from 0.06 A U to

about 0.25 A U. On account of its similarity to the continuous spectrum of the sun it is called the "white light" spectrum. The lower limit of the continuous spectrum depends according to the Planck-Einstein law on the maximum value of the voltage applied to the tube. The quantitative relation between the shortest wave length and the maximum (peak) voltage has been determined by Duane and Hunt. It is given by the equation

$$V = \frac{12.358}{\lambda}$$

where V is the maximum value of the voltage expressed in kilovolts and λ the wave length expressed in Angstroem units. In this form the equation can be used to calculate directly the voltage required to produce any desired limiting wave length. For example, in order to produce a spectrum with 0.06 A U as its lower limit.

$$V = \frac{12.358}{0.06} = 205$$

Thus 205 K V are required.

In order to produce a Roentgen radiation similar to the radiation of radium with a lower limit of 0.01 A U a voltage of

$V = \frac{12.358}{0.01}$ or 1230 K V or a voltage of 1¼ million volts would be necessary. This value cannot be taken as exact since the lower limit of the radium radiation is not definitely known. The formula can also be written

$$\lambda = \frac{12.358}{V}$$

It is then in a convenient form for calculating directly the limiting wave length corresponding to a definite kilovoltage.

For $V = 200$ K V the exact value of the shortest wave length is

$$\lambda = \frac{12.358}{200} = 0.0615 \text{ A U.}$$

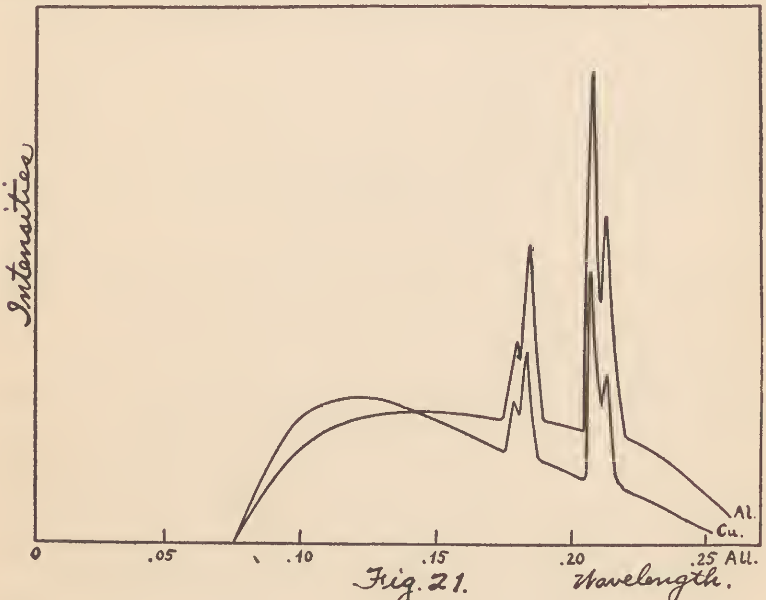
For $V = 250$ K V it would be

$$\lambda = \frac{12.358}{250} = 0.0492 \text{ A U.}$$

The law of Duane and Hunt can be deduced theoretically on the basis of the Quantum theory of Planck and has been verified experimentally over a wide range of wave lengths. The formula shows that the wave length depends neither on the frequency nor the wave form, but depends only on the maximum value of the voltage.

Nothing very exact can be said regarding the upper limit of the continuous spectrum. An accurate measurement of the upper limit is impossible since it is obscured by the second order spectrum; neither can any simple relation be deduced theoretically. The intensity does not fall to zero but decreases continuously to smaller and and smaller values, which approach the value zero asymptotically. However, in practice there does exist an upper limit which is determined chiefly by the filtration used but depends to some extent also upon the shape of the voltage wave. The greater the thickness of filter and the smaller the ratio of the maximum value to the lower values of the instantaneous voltages, the lower will be the upper limit of the continuous spectrum. With different transformers and rectifiers, various filter thicknesses are required to limit the spectrum at the upper end. The distribution of intensity between these limits depends on many factors; the peak voltage, the form of the voltage wave, the filter thickness, and the filter substance. The last was proved by Duane, who investigated

two spectra with identical electrical conditions but with copper as filter in the one case and with enough aluminum in the second case to reduce the intensity until it was the same as with copper according to an ionization measurement. Figure 21 shows that the distribution of intensity is very different in the two cases; it can be seen that the maximum lies at different points.



Spectra, 161 K V, Constant Potential, Filtered (a) ½ M M Cu, (b) 12 MM Al. (Duane.)

The composition of the continuous spectrum depends on the direction in which the rays emanate. Wagner investigated this phenomenon and obtained the most reliable results. He examined the radiation emerging at the angles of 90° and 150°, as shown in Figure 22.

At angles of 90° or less, maximum intensity and hardness was observed. At an angle of 150° or for radiation traveling in a backward direction, the intensity of the

harder components is diminished by 37%, while that of the softer components is diminished by only 23%. Hence in this direction the radiation is not only less

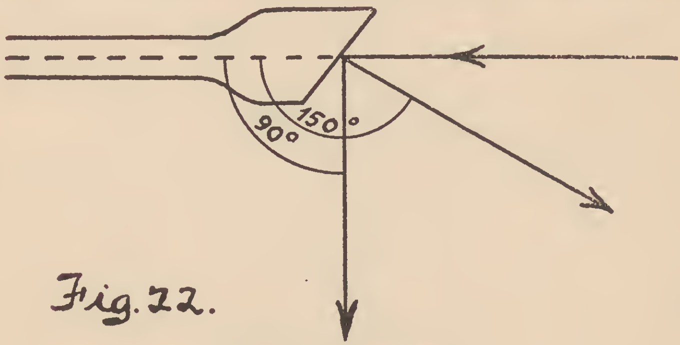


Fig. 22.

Effect of Direction.

intense but softer as well. The lower limiting wave length is the same for all directions, in agreement with the Planck-Einstein law.

This fact becomes noticeable when measurements and irradiations are carried out at improper angles.

A spectrum is determined to a large extent by the position of its two limits and its maximum, but not completely, chiefly on account of the fact that a discontinuous spectrum is superposed on the continuous spectrum.

The discontinuous spectrum consists of a large series of narrow lines, which occur in groups. For this reason the discontinuous spectrum is also called the line spectrum. It has also been termed the characteristic spectrum since it depends on the kind of material emitting the rays. The line spectrum exhibited by a tube with a tungsten target is different from that of a tube with a platinum target. The characteristic spectrum of an element is determined b its place in the periodic system of the elements. Each element can be given an "atomic

number" depending on its place in the periodic system. The table given in Figure 23 gives the names, atomic weights and atomic numbers of all the known elements.

1 H 1.0																															2 He 4.0
3 Li 6.9	4 Be 9.1	5 B 11.0	6 C 12.0																									7 N 14.0	8 O 16.0	9 F 19.0	10 Ne 20.2
11 Na 23.0	12 Mg 24.3	13 Al 27.1	14 Si 28.3																									15 P 31.0	16 S 32.1	17 Cl 35.5	18 A 39.9
19 K 39.1	20 Ca 40.1	21 Sc 44.1	22 Ti 48.1															23 V 51.0	24 Cr 52.0	25 Mn 54.9	26 Fe 55.8	27 Co 59.0	28 Ni 58.7	29 Cu 63.6	30 Zn 65.4	31 Ga 69.6	32 Ge 72.5	33 As 75.0	34 Se 79.2	35 Br 79.9	36 Kr 82.9
37 Rb 85.5	38 Sr 86.6	39 Y 88.7	40 Zr 90.6															41 Nb 93.5	42 Mo 96.0	43 —	44 Ru 102	45 Rh 103	46 Pd 107	47 Ag 108	48 Cd 112	49 In 115	50 Sn 119	51 Sb 120	52 Te 127.5	53 I 126.9	54 X 130
55 Cs 133	56 Ba 137	57 La 139	58 Ce 140	59 Pr 141	60 Nd 144	61 —	62 Sm 150	63 Eu 152	64 Gd 157	65 Tb 159	66 Dy 162	67 Ho 164	68 Er 168	69 Tu I 169	70 Ad 174	71 Lu 175	72 Tu II 178	73 Ta 182	74 W 184	75 —	76 Os 191	77 Ir 193	78 Pt 195	79 Au 197	80 Hg 201	81 Tl 204	82 Pb 207	83 Bi 208	84 Po 210	85 —	86 Em 222
87 —	88 Ra 226	89 Ac 227	90 Th 232															91 Pa 231	92 U 238												

Fig. 23.

Periodic System of the Elements.

Moseley found a simple relation between the wave length of the characteristic radiation and the atomic number of the elements. This relation is exhibited graphically in Figure 24.

It is seen that the wave length decreases progressively with increasing atomic number. This relation is so exact that it can be used to determine where elements are still missing in the periodic system; for a missing element means a discontinuity in the curve. The relation found by Moseley can also be used to decide the correct order of those elements which on the basis of atomic weights would be placed in the reverse order. These elements are

Argon—Potassium
Cobalt—Nickel
Tellurium—Iodine
Thorium—Protoactinum.

The characteristic spectra are divided into the K, L and M series; of these the K series is the hardest; the L series is relatively soft and falls in the short wave length

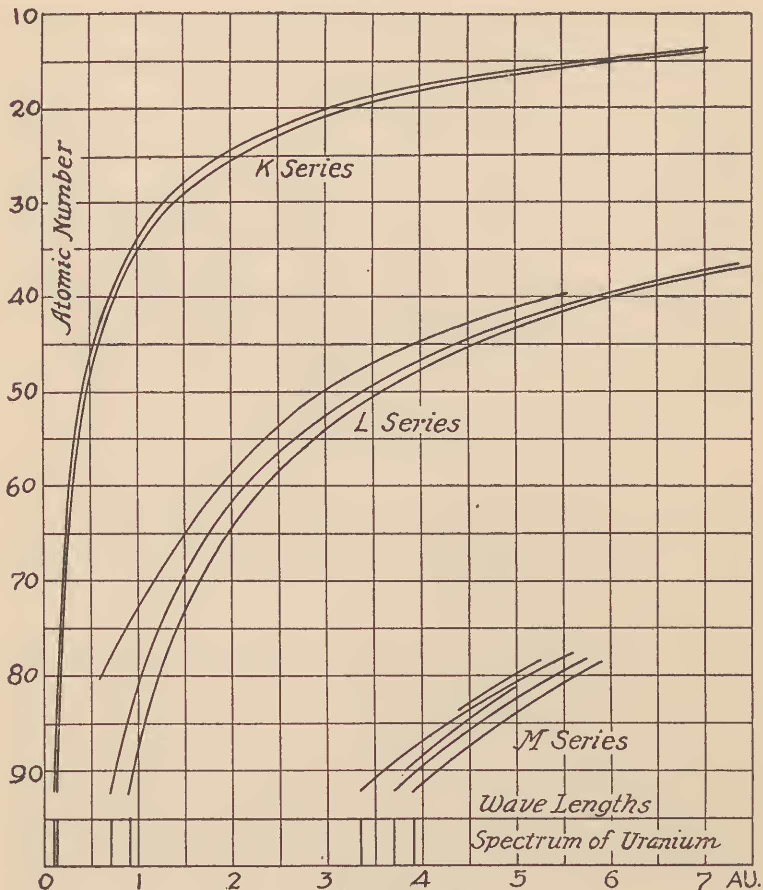


Fig. 24

Relation between Characteristic Radiation and Atomic Number of the Elements.

regions only for high atomic weights. The M series is extremely soft even for very high atomic weights and need not be considered in deep therapy.

The K series consists of two lines, each of which is again complex. This is shown by the graphical representation of the tungsten spectrum according to Duane (Figure 21). The wave lengths of the tungsten lines are important since they are convenient values for orientation in the spectrum, they are:

α_2 ....0.2135 A U
α_1 ....0.2088 A U
β_1 ....0.1844 A U
β_2 ....0.1794 A U

The figure also shows that the characteristic rays under the conditions used for deep therapy lie on the side of the maximum toward longer wave lengths, that is to say they make the total radiation softer. The characteristic K radition of uranium is much harder, it would lie on the shorter wave length side of the maximum and so increase the intensity of the hard radiation. This is one reason for the attempt to use uranium in place of tungsten for the anticathode.

Filters and protective substances also emit characteristic radiation when Roentgen rays strike them. The K radiation of copper, for instance, lies in the neighborhood of 1.5 A U which is in the region of the soft rays used for diagnostic purposes. Since they would be strongly absorbed by the skin it is advisable to absorb them with ½ or 1 millimeter of aluminum. The characteristic radiation of aluminum lies in the neighborhood of 8 A U. It is so soft that it does not reach the living layers of the skin at all but is completely absorbed by the overlying dead tissues and by the air. Doubtless characteristic radiation is also excited in the interior of the human body by the effect of the Roentgen rays on the hydrogen, carbon, oxygen and nitrogen atoms. The wave length of the

characteristic K radiation of carbon and oxygen has recently been determined by Holtzmark and Kurth as 42.6 (42.9) and 23.8 A U. The wave length of the corresponding L radiation is 375 and 248 A U. Such rays are completely non-penetrating; they are at once absorbed and transformed into electronic motion.

Lead also gives off characteristic radiation. Its K radiation is very hard, $\lambda = 0.15$ A U, hence penetrating and not dangerous. However, the L radiation of lead lies at 1 A U, between 0.79 and 1.35 A U. This soft radiation can in some cases do considerable damage. With sufficient filter thickness all primary radiation is absorbed; hence no characteristic radiation can be produced on the side away from the tube. On the other hand a soft radiation comes from the side toward the tube; also when the filter is not of sufficient thickness characteristic radiation can emerge from the side opposite the tube. This soft radiation can be absorbed by rubber, leather or linen. For this reason lead should not be placed directly on the skin. The latter should be protected with a cloth or rubber covering. This is also more sanitary and besides protects the patient against static charges.

Also if radium rays are filtered through lead an intense secondary radiation is produced; it can be absorbed sufficiently by 0.2 millimeters of aluminum.

Characteristic radiation of a given hardness is produced only by the absorption of harder rays. The characteristic radiation of copper is excited only when rays of shorter wave length than 1.5 A U penetrate the copper. Again the characteristic K radiation of tungsten is excited only when a greater voltage than that corresponding to the K radiation of tungsten is applied to the

tube. This phenomenon is very similar to the phenomenon of fluorescence observed with ordinary light. The characteristic radiation is therefore also called fluorescent radiation.

In the following table the average wave lengths of the characteristic radiations of a number of important elements are given:

Element	Kβ	Kα	Element	Kβ	Kα
Al	7.96 A U	8.30 A U	Wo	0.180 A U	0.210 A U
Cu	1.39 A U	1.54 A U	Ir	0.168 A U	0.188 A U
Zn	1.30 A U	1.44 A U	Pt	0.159 A U	0.183 A U
Ag	0.50 A U	0.56 A U	Ur	0.108 A U	0.130 A U
Sn	0.43 A U	0.49 A U			
Pb	0.14 A U	0.16 A U			
	L				
Pb	1.0 A U				

The elements in the left hand column are of importance as filters and protective material: those in the right as anticathode metals.

On account of the complex mixture of discontinuous and continuous spectra in an ordinary spectrum it is impossible to estimate or deduce an average value of the wave length from which conclusions as to the general properties of the radiation could be drawn. However, for the purposes of deep therapy a knowledge of the average hardness is more important than a knowledge of the composition of the beam.

Acting on this idea Duane has introduced the concept of effective wave length. In any unhomogeneous beam there always exists a homogeneous radiation of a definite wave length, which would be absorbed in the

same ratio by a given filter, say 4 millimeters of aluminum, as the beam as a whole. A really heterogeneous radiation can therefore be thought of as replaced by a homogeneous radiation of a definite wave length.

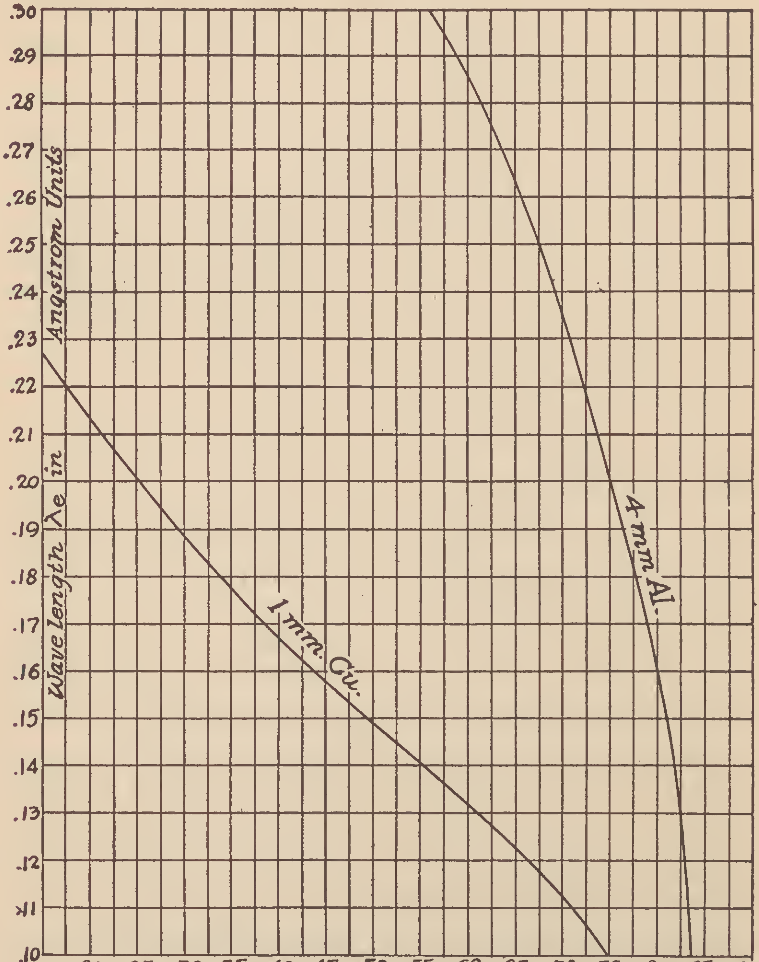


Fig 25

Percentage of Roentgen Rays Passing Through 1 MM Copper and 4 MM Aluminum for Various Effective Wavelengths.

Duane defines the effective wave length of a mixed beam as the wave length which shows the same property (absorption in aluminum or copper of a definite thickness) as the mixture. He proposes that the percentage of radiation penetrating 4 millimeters aluminum or 1 millimeter of copper be determined. From the curves given in Figure 25 together with an absorption measurement the effective wave length can be deduced. The absorption measurement is best carried out with an electroscope as follows:

The regular filter, say ¾ millimeter copper and 1 millimeter of aluminum, is put in place; one measurement is made without the auxiliary filter (4 millimeters aluminum) and a second made with the auxiliary filter.

The measurements are made alternately a number of times about as follows:

	No filter	mm Al
Discharge time	13.6	
		16.6
	13.5	
		16.9
	13.8	
		16.8
	13.5	
Average value	13.6	16.8
Ratio	81.	100

The two discharge times 13.6 and 16.8 are in the ratio of 81 : 100. Now the intensities are in the inverse ratio—a long discharge time corresponds to a low intensity. The intensities are therefore in the ratio of 100 : 81, i.e. 81% of the incident radiation is transmitted by the filter, the

remainder, 19% being absorbed. Next, the value corresponding to a penetration of 81% is read off from the graph. One follows the vertical line at 81 upward to the curve and then proceeds along the horizontal line to .15 A U.

If the same measurement is carried out with a copper filter, it is found that 55% of the incident radiation is transmitted, which from the curve at the left gives a value of 0.14 A U. The difference in wave length is explained by the greater absorption of soft rays by the heavier filter. Human tissue also filters out the soft components. As far as the hardness of the radiation is concerned, a filter of 4 millimeters of aluminum corresponds to a thickness of tissue of 3 to 3.5 centimeters, a filter of 1 millimeter of copper to 7 to 7.5 centimeters of tissue. Hence the aluminum filter is a better measure of the effective wave length near the surface; the copper filter gives us more information about the effective wave length at a greater depth.

A statement of the effective wave length is a very simple and practical definition of the hardness of the radiation; it is based on an absorption measurement and therefore can be used to give information regarding the depth distribution, which also depends on absorption. The measurement of the effective wave length by absorption is much simpler than any other method for the measurement of hardness.

§2. Practical Definitions of Hardness.

In Roentgen ray practice the endeavor to attain a simple method of describing the penetrating property of the rays has led to a number of definitions of hardness or penetration.

The attempt here has not been to formulate a theoretically exact definition of quality but rather to obtain a working definition of the penetration of the rays into the tissues, taking into account the various factors which influence this penetration.

These factors are:

(a) Focus skin distance;

(b) Absorption;

(c) Scattering.

That the focus skin distance is an important factor in determining the penetration of the rays into the tissues is easily seen from the following example:

(a) In place of the patient a phantom consisting of an air filled sphere 20 centimeters in diameter is used; the distance between the target and the surface of the sphere is made 30 centimeters; and the intensity at the surface is taken as 100.

What will be the intensity at the center, that is at a depth of 10 centimeters?

According to the inverse square law

$$
\begin{aligned}
x : 100 &= 30^2 : (30 + 10)^2 \\
&= 30^2 : 40^2 \\
&= 9 : 16 \\
&= 0.56 \\
x &= 56\%.
\end{aligned}
$$

Now let the distance be increased to 50 centimeters, but let the intensity at the surface be made the same as before by increasing the milliamperage. What will now be the intensity at the center?

$$
\begin{aligned}
x : 100 &= 50^2 : 60^2 \\
&= 25 : 36 \\
&= 0.695 \\
x &= 69\tfrac{1}{2}\%.
\end{aligned}
$$

The intensity at the same depth relative to the intensity at the surface is therefore appreciably greater with a greater focus skin distance.

This result can be verified with an iontoquantimeter.

(b) Next let us make the following experiment (Figure 26):

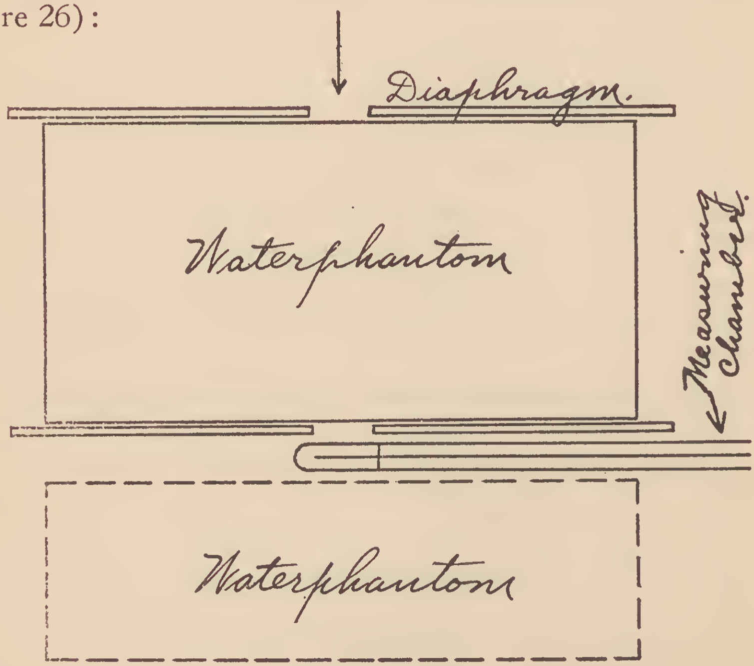


Fig. 26.

The Effect of Scattered Radiation on the Depth Dose.

The measuring instrument is placed 50 centimeters from the target and a box some 10 centimeters high, which can be filled with water, is interposed. Two lead diaphragms, each with a circular aperture 1 centimeter in diameter, are placed one above and one below the box. Measurements are made both with the box empty and with the box filled with water. They show that

approximately 1/5 (accurately 19%) penetrates the water, the remainder or 81% is absorbed by the water. It is important to note that the distance of the chamber from the target was not changed during the experiment. Hence it is immaterial whether a distance of 50 centimeters or one of 30 centimeters is used. In this case the total loss of intensity is the result of absorption of the rays in the water. The amount of absorption depends on the wave length of the radiation; the exact relation between the two is given in Chapter III.

(c) Now let both diaphragms be removed and let the measurements be repeated with and without water. Instead of a narrow pencil of rays a broad beam now passes through the water. The intensities with and without the water are now found to be in the ratio of 100 : 45, i. e., 45%, now passes through and 55% is absorbed.

The difference in results obtained in experiments (b) and (c) is explained by the fact that there are two kinds of absorption; true absorption and absorption due to scattering.

(1) True absorption is a transformation of the energy of Roentgen radiation into other forms, such as soft characteristic radiation, ionic and electronic motion, heat, etc.

The soft characteristic radiation of water is immediately absorbed at the point where it originates and is transformed into electronic motion. The electronic motion also goes over into heat; in some substances chemical changes occur; in living tissues biologic reactions are produced; and all these phenomena involve a loss of primary Roentgen energy. This loss due to transformation is called true absorption.

(2) Absorption due to scattering: Roentgen rays are bent from their course whenever they pass through

matter; that is, they are scattered. If a narrow pencil of rays passes through matter, these scattered rays are lost to the pencil, they merely give up a small amount of energy to the surrounding medium. If, however, a large volume is subjected to radiation the scattered rays proceeding from any one pencil add to the primary radiation adjacent. What is lost by one pencil of the beam is compensated for by the neighboring pencils; this is especially true for the central ray around which the primary radiation is uniformly distributed. On this account a much smaller loss of absorbed energy is found by a measurement.

In experiment (b) the absorption found for the narrow beam is due to both true and scattered absorption. In example (c) most of the scattered energy is returned and we have practically only true absorption.

Experiment (c) can be still further developed, see again Figure 26. A second water phantom is placed behind the ionization chamber, where before there was no scattering medium. A new measurement shows that the intensity has increased from 45% to 56%. By the medium which now completely surrounds the chamber an additional 11% is reflected back to it. The chamber now lies entirely within a scattering medium and receives the maximum of scattered radiation.

These examples show on what factors the intensity in the interior of a medium depends. In these particular instances water was used as the absorbing medium. Experiment and theory have shown that body tissue behaves on the average toward Roentgen rays and radium rays much the same as does water. In Chapter III the behavior of other matter toward Roentgen rays will be further discussed.

Absorption and scattering have a definite relation to the wave length and can therefore serve as a measure of the quality of the radiation. However, other factors, like the focus skin distance and the volume subjected to radiation, somewhat complicate the relations.

With this idea in mind we shall discuss a few of the hardness definitions used in practice.

(a) The "percentage decrease per centimeter" gives the decrease of intensity in per cent from centimeter to centimeter. This decrease depends

(1) On the wave length of the radiation. Not only the average (effective) wave length but the composition of the beam is a determining factor.

(2) On the focus skin distance—the larger the focus skin distance the smaller the per cent decrease.

(3) On size of field—large fields show a smaller decrease.

(4) On the depth—the decrease is not uniform; it is smaller in the first centimeter than in the deeper ones. The exact relations are shown in Chapter III.

(b) The "half value layer."

This is defined as the depth (in centimeter) at which the intensity is reduced to half its value at the surface.

This depends on

(1) Effective wave length

(2) Focus skin distance

(3) Size of field.

(c) The "depth dose." This is defined as the intensity at 10 centimeters depth expressed in per cent of the intensity at the surface.

A depth dose of 40% means that 40% of the intensity at the surface reaches a depth of 10 centimeters.

The depth dose depends on

(1) Effective wave length

(2) Focus skin distance

(3) Size of field.

In all cases cited the extent of the surrounding medium (diameter of patient) also enters as an important factor.

The depth dose is the most widely used definition of penetration; for this reason the experimental determination of this quantity will be discussed in detail.

The best apparatus for this purpose is an iontoquantimeter with a small chamber. In order to make the measurement accurate, the chamber must be of small dimensions and must be symmetrically surrounded by water or a similar substance. Metallic substances, which absorb strongly and scatter considerably, should not be placed in the immediate neighborhood of the chamber.

An iontoquantimeter constructed by the author satisfies these requirements. (Figure 15.)

Iontoquantimeters with large boxlike chambers do not measure the complete scattered radiation and give results about 15% low for the depth dose. The selenium cell of Fuerstenau also does not measure the full amount of scattered radiation and gives too low a value for the depth dose. Electroscopes of course cannot be used for these measurements.

The iontoquantimeter is best used with a water phantom. Wooden cubes filled with water are very convenient. Bodies of various shapes can be built up out of them and measurements made at various depths and along at the sides. With a water filled container only rays coming from above can be measured conveniently.

In setting up the apparatus a number of sources of error must be carefully avoided.

(1) For surface measurements the chamber must not lie above or below the surface. In the first position too little and in the second too great an intensity would be measured. The third position gives approximately correct values. For this reason a wooden (oak) board cut to receive the chamber and of about half the thickness of the chamber is used. The surface of this board and therefore the center of the chamber must be at the chosen focus skin distance from the target (50 centimeters).

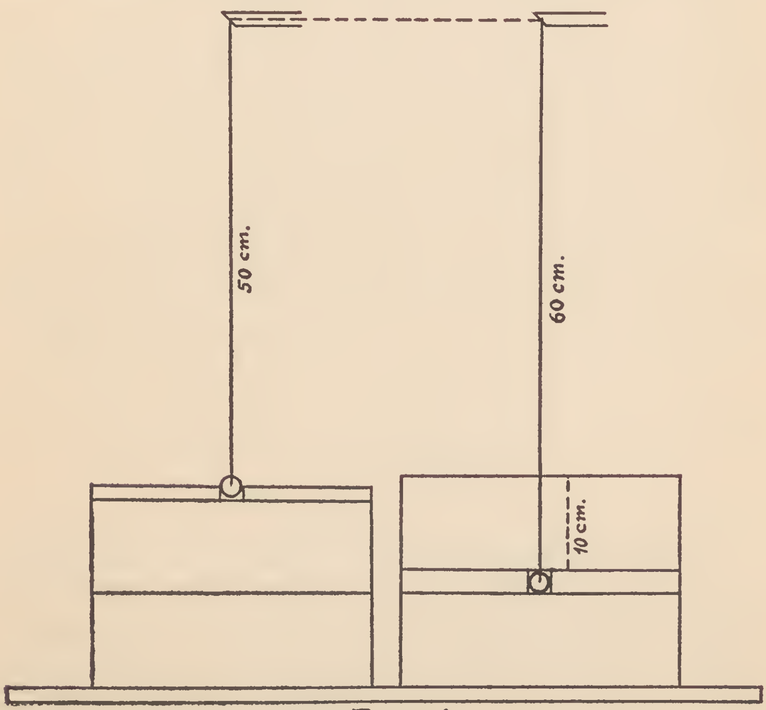


Fig. 27.

Correct Measurement of the Depth Dose with a Small Ionization Chamber.

(2) In passing from the surface to the depth measurement, the chamber must be lowered exactly 10 centimeters.

(3) Also at a depth the chamber must be surrounded by the scattering medium. Above the chamber there must be exactly 10 centimeters of the medium, below the chamber at least this distance, and toward the sides a greater distance than 10 centimeters.

The exact arrangement is shown in Figure 27.

It is seen that with this arrangement the increment in focus skin distance as well as the increment in the irradiated medium is exactly 10 centimeters.

If a chamber 2 centimeters in thickness were immersed 10 centimeters below the surface, only 9 centimeters of absorbing substance would be interposed; if 10 centimeters were interposed, the increment in focus skin distance would be 11 centimeters. These sources of error are avoided by the above arrangement.

At the surface, as well as at a depth of 10 centimeters, the measured discharge time must be corrected for leak discharge according to the formula given in Chapter I.

If the corrected value of the time at the surface is t_s and that at a depth t_d then the intensities are in the inverse ratio and the depth dose in per cent is given by:

$$D = 100 \frac{t_s}{t_d}$$

Similar measurements can be made of the hardness or of the depth distribution of radium rays. The rapid change of intensity, due to the smaller distances used in radium technique, makes it necessary to employ very small chambers. On account of the resulting small ionization current, the measuring instrument must be very sensitive and well shielded against the penetrating gamma rays.

As the last of the practical definitions of quality let us consider the total absorption coefficient μ. While the various definitions considered so far are not accurately defined but depend on a number of factors, the total absorption coefficient is independent of the focus skin distance and size of field.

Let us refer again to the above experiment on the absorption of a narrow pencil of rays by water. If the water phantom is interposed without changing the distance between target and chamber the result of the measurement is entirely independent of this distance. On account of the small cross section of the beam no appreciable amount of scattered radiation returns from the interior of the water. Hence this measurement gives the total absorption resulting from the addition of true absorption and absorption due to scattering. The definition of the absorption coefficient is given by a formula, the derivation of which cannot be discussed here, but which can be used for the measurement and the computation of μ.

The formula is

$$\mu = \frac{\log \frac{t_o}{t_f}}{d \times 0.4343}$$

where t_o is the discharge time without the absorbing medium and t_f with the absorbing medium. d is the thickness of the absorbing layer in centimeters.

The calculation is simplest if a layer 2.3 centimeters thick is used, for then the denominator becomes equal to 1 and the formula becomes

$$\mu = \log \frac{t_o}{t_f}$$

The best method for determining μ is that employing the electroscope. For this purpose an electroscope with a long entrance tube provided with two diaphragms is used and a water phantom 2.3 centimeters in thickness is inserted between the two diaphragms. The arrangement is shown in Figure 28.

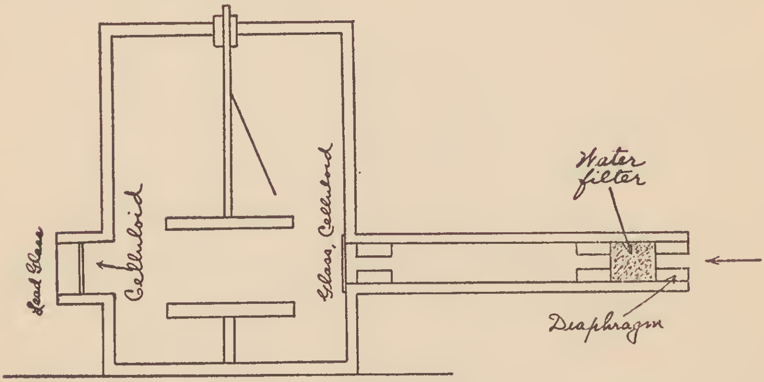


Fig. 28.

Diagram of the Electroscope—μ Measurement.

The total absorption coefficient μ is used a great deal in physical literature to define the quality of the radiation. The measurement of μ is not very simple. The values obtained vary somewhat. The author is of the opinion as regards the total absorption coefficient that a determination of the effective wave length by means of aluminum or copper is simpler and that a statement of the depth dose is more valuable for the purposes of deep therapy.

A simple numerical relation exists between the total absorption coefficient μ and the half value layer h as follows:

$$h = \frac{1.7}{\mu}$$

This equation can be used to calculate the total absorption coefficient if the half value layer is known and vice versa.

Recent measurements by Compton have shown that the scattered radiation is somewhat softer than the primary radiation. The difference in hardness is the same for all wave lengths (a range from 0.7 A U to 0.025 A U was examined) and amount to 0.022 A U in the direction of the primary ray. In other directions the difference is greater, being 0.03 A U at right angles to the direct ray and 0.068 A U at 135°. Since the scattered radiation is a large fraction of the total radiation, its diminished penetration is of importance. Although the change in wave length of the Roentgen rays used in deep therapy (λ effective = 0.15 A U) is only 15%, for strongly filtered gamma rays it becomes relatively large. By one reflection the wave length may change 100%, and by successive reflections in a large rayed medium a much greater change is to be expected.

This complex and heterogeneous composition of the radiation in the interior makes accurate dosage difficult. The errors introduced into measurements by varying hardness can be considerable; they can best be excluded by the use of measuring devices which indicate the biologic action. To this class belong the biologic methods of measurement and the Friedrich method (to be described later) which employs a properly dimensioned small ionization chamber of horn.

An important difference exists between the type of radiation considered so far (the Roentgen radiation and the gamma radiation of radium) and the alpha and beta radiations of radium. The alpha and beta rays are mate-

rial particles(helium nuclei and electrons, respectively) which are projected with high velocities from the decomposing radium atoms.

The initial velocity of the alpha rays amounts to approximately 10,000 miles per second (more exactly $1.5 \times 10^9 — 2.0 \times 10^9$ centimeters per second); the initial velocity of beta particles reach a velocity 99% that of light.

While in the case of Roentgen rays and gamma rays we speak of a spectrum corresponding to the range of wave lengths represented, in the case of alpha and beta rays we also speak of a "spectrum" corresponding to the range of velocities.

For the propagation of corpuscular rays in vacuo the same law of distance holds as for Roentgen rays and radium rays: the intensity varies inversely as the square of the distance. However, an important difference exists between the two types of radiation. In the case of a wave motion it is the decrease in the amplitude of vibration which diminishes the intensity; even at large distances from the source the radiation covers continuously the surfaces on which it falls. In the case of corpuscular radiation the situation is very different; the further the radiation is from the source, the more apparent is its corpuscular nature—particularly in that the rayed surface can be resolved into a number of rayed points. In this case the intensity of the single rays is conserved and it is the concentration of the rays which decreases.

The penetration of the rays depends to a high degree on their velocity. In passing through matter the rays supply energy at the expense of their velocity. Hence the penetration of the rays decreases as they pass through

matter; moreover, after they have traveled a certain distance the rays suddenly cease to exist.

To each type of radiation, depending on the nature of the radiation (that is whether it is alpha or beta radiation), the velocity of the ray, and the nature of the rayed medium, there corresponds a definite length of path (range) beyond which the rays cease to exist. At the end of the range the rays encounter the strongest absorption and therefore produce at this point their greatest ionizing and biologic effect.

For this reason the effect of a homogeneous radiation on its way through tissue does not vary according to an exponential law (as stated erroneously, for example by Simpson). If, on the contrary, we deal with a mixture of hard rays of different wave lengths, the effects of the various components are superimposed in such a way that the resulting effect follows an exponential law approximately. Hence the definitions of hardness already discussed can also be applied with a certain approximation to alpha and beta rays and, for example, a half value layer of the alpha and of the beta rays defined.

The range of the alpha rays of radium and its radioactive products varies from 4 to 7 centimeters in air. The half value layer of tissue is about 0.03 millimeters. One-third millimeter of tissue absorbs practically the whole radiation. Thus most of the rays are absorbed in the dead outside layers of the skin, and only a small percentage strikes the living tissue. Of course, only surface applications produce rays; the glass containers of an emanation ampule and the filters of other containers absorb them completely.

For the absorption of the beta rays of radium a much

greater thickness is necessary the following thicknesses being required for the absorption of 50% (half value layer) and 99%, respectively.

Material	50%	99%
Water, tissue, rubber	1.00 mm	8.50 mm
Glass, aluminum	0.40 mm	3.30 mm
Brass, nickel, copper	0.13 mm	1.10 mm
Silver	0.11 mm	0.90 mm
Lead	0.10 mm	0.80 mm
Gold	0.06 mm	0.50 mm
Platinum	0.05 mm	0.40 mm

According to the table 1.5 millimeters brass or ½ millimeter of silver plus 1 millimeter of brass absorbs practically all the beta radiation. The walls of the radium needle, 0.35 millimeters of non-corrosive steel absorb only a part (about 95%) of the beta rays hence an additional 1 millimeter of copper or of brass is necessary to absorb practically all the beta rays.

The following table applies to the hard gamma rays filtered by 1.5 millimeters of brass:

Material	50%	99%
Water, tissue	20-25 cm	
Brass	2.0 cm	14.0 cm
Lead	1.4 cm	9.2 cm

This illustrates the extreme penetration of the gamma rays of radium compared to the alpha and beta rays as well as the hardest rays emitted by the X ray tube.

Quimby has called attention to an important fact regarding the absorption of beta and gamma rays by the metals commonly used as filters.

When thin equivalent thicknesses of lead, aluminum, and brass are used to filter the radiation emanating from radium preparations, it is found that the lead suppresses the beta rays to a greater extent than does the brass or aluminum. The lead filtered radiation is therefore more penetrating than the other two. This holds for thicknesses up to ½ mm of lead and the corresponding (equivalent) thicknesses of aluminum and brass. Greater thicknesses absorb nearly all the beta rays. However, from this point on, the phenomena of selective absorption and emission becomes noticeable; the lead absorbs part of the harder gamma rays, transmits the softer ones, and furthermore, emits characteristic K radiation. Hence part of the radiation filtered by lead is softer than that filtered by aluminum and brass. For the production of very penetrating gamma rays brass is to be preferred to lead, whenever it is not urgent to employ very thin filter thicknesses. An especially good combination is that of silver and brass since the two absorption curves dove tail fully as well as do the two silver and copper curves. See Figure 29 on page 130.

Chapter III

Distribution of Roentgen and Radium Rays in Various Media

After a discussion of definitions and methods of measurement, we shall now turn to the laws which apply to the penetration of rays through matter and consider the question of the distribution of energy in a rayed medium.

§1. Laws of absorption and scattering.

We shall first consider the laws of absorption:

Total absorption is made up of true absorption and absorption due to scattering. In addition to the total absorption coefficient, a coefficient of true absorption and a coefficient of scattering can be defined. We shall not concern ourselves with the exact definitions, suffice it to say that the respective coefficients represent the amount of absorption and of scattering and may be used for quantitative comparisons.

Let the coefficient of true absorption be represented in the usual way by $\bar{\mu}$; the coefficient of scattering by σ; and the coefficient of total absorption by μ.

These quantities are connected by the relation

$$\mu = \mu + \sigma$$

This equation merely states that the total absorption is the numerical sum of the true absorption and the absorption due to scattering.

Simple laws apply to the true absorption and to the scattering. The laws governing total absorption are more complex because they are obtained by the additive combination of the others.

True absorption depends to a high degree on the wave length. It increases with the wave length, varying approximately as the cube of the wave length (more exactly as the 2.8 power). To compare the two wave lengths

$$\lambda_1 = 0.2 \text{ A U},$$
$$\lambda_2 = 0.4 \text{ A U},$$

with respect to true absorption, we have to form the proportion with the cubes of the wave lengths. We have accordingly:

$$\begin{aligned} \mu_1 : \mu_2 &= \lambda_1^3 : \lambda_2^3 \\ &= 0.2^3 : 0.4^3 \\ &= 8 : 64 \\ &= 1 : 8. \end{aligned}$$

If one radiation has double the wave length of another, it will be absorbed about eight times as strongly as the other (accurately seven times as strongly). Two beams whose wave lengths are in the ratio of 1 : 3 will be absorbed roughly in the ratio of 1 : 22.

On this law the action of filters is based.

Rays of long wave lengths are so strongly absorbed by the tissues that their energy overexposes the surface layer, i. e., the skin. Rays of short wave length are absorbed to a lesser degree and are distributed over a larger region and therefore are less likely to do damage.

If a filter of aluminum or of copper is interposed, the softer rays are stopped and do not reach the tissues. In deep therapy the problem is not to suppress alone the very soft rays but to transmit only the very hardest. For this reason heavy filtration must be used.

The following table, although not perfectly general, gives an idea of the proper filtration to be used in deep therapy. Weaker filtration would pass too much soft

radiation; stronger filtration would diminish the intensity too much.

Kilovolts, peak value	Cu filter	Shortest λ	Effective λ	Longest λ
140 K V	0.5 mm	0.088 A U	0.19 A U	— A U
160 K V	0.6 mm	0.077 A U	0.17 A U	— A U
180 K V	0.7 mm	0.069 A U	0.16 A U	0.30 A U
200 K V	0.8 mm	0.062 A U	0.14 A U	0.28 A U
220 K V	1.0 mm	0.056 A U	0.12 A U	0.26 A U

Such strongly filtered rays are frequently called "practically homogeneous" radiation. This expression, as can be seen from the table, is hardly justified for the spectrum extends over a large region—more than 2 octaves, if the interval corresponding to a ratio of wave lengths of 1 : 2 be designated as an octave.

The relation between absorption and wave length can be represented graphically (Figure 29).

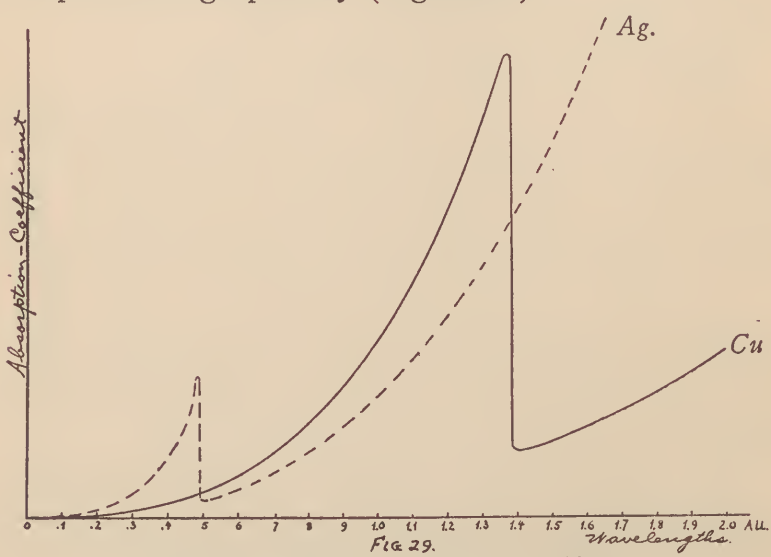


Fig 29.

Absorption Curves of Copper and Silver.

The full curve shows the variation of the absorption with the wave length for copper. It will be noticed that the curve is discontinuous at one point; with increasing wave length the absorption suddenly decreases to very low values. In this region softer rays are actually absorbed to a lesser degree than the harder ones.

Every element has a characteristic discontinuity in its absorption curve. This point lies just below the point of characteristic emission. The following table gives the characteristic K wave lengths and the edges of the absorption bands, as these points of discontinuity have come to be known, for a few elements useful in Roentgen practice.

Element	Atomic Number	λ Absorption Band	λα	λβ
Al	13	7.9470 A U	8.30 A U	7.96 A U
Cu	29	1.3785 A U	1.54 A U	1.39 A U
Zn	30	1.2963 A U	1.44 A U	1.30 A U
Pb	82	0.1412 A U	1.16 A U	0.14 A U
Wo	74	0.1783 A U	0.210 A U	0.180 A U
Ir	77	0.167 A U	0.188 A U	0.168 A U
Pt	78	0.1582 A U	0.183 A U	0.159 A U
Ur	92	0.1075 A U	0.130 A U	0.108 A U
Br	35	0.9179 A U	1.035 A U	0.929 A U
Ag	47	0.4850 A U	0.562 A U	0.501 A U

The table shows that the region of transparency and characteristic radiation for copper lies above 1.37 A U, for zinc lies above 1.29 A U.

An aluminum filter readily absorbs these wave lengths. Its characteristic radiation and region of transparency is in the range of extremely soft rays: namely, above 8 A U.

The table shows also that lead cannot be considered for filter material; its point of discontinuity lies inside the range of wave lengths used for deep therapy. That is to say, in this range lead absorbs hard rays and transmits soft rays. Also all the elements used for anticathodes: tungsten, iridium, platinum, uranium, are not to be recommended as filters.

Besides copper, silver is used for filtering radium rays. The two absorption curves of these metals dovetail well, as a glance at Figure 29 will show. However, the silver should not be used alone as it emits and transmits medium soft rays.

Silver and bromide play an important part in spectrum photography and in photographic measurements of intensity and energy:

On every spectrum photograph two points of discontinuity are observed, corresponding to the wave lengths 0.485 A U and 0.918 A U. One of these is illustrated in Figure 20. At a point corresponding to the wave length 0.485 A U, the blackening changes abruptly from a dark to a light shade. This phenomenon is due to the selective absorption of the silver in the photographic emulsion. Silver absorbs those rays whose wave lengths are less than 0.485 A U more strongly than it does those whose wave lengths are greater than 0.485 A U. This defect of the plate is not likely to become a source of error in spectroscopy since the phenomenon is now well known. These places of discontinuity can, moreover, serve as convenient reference points. However, the situation is very different from photographic films (Kienboeck strips) are used for measuring intensity.

If the intensities of two radiations, one of which has

a wave length lying above the point of selective absorption and the other of which has a wave length lying below it, are compared by the photographic method, the harder radiation will be measured too strong relative to the other. The photographic measurement in this case is subject to an error due to the effect of hardness.

All measuring instruments are subject to errors due to hardness—the Fuerstenau intensimeter, for example, due to the use of selenium as the active material. The point of discontinuity in the selenium absorption curve is at 0.99 A U. The conducting wires, as well as the core on which they are wound, and the carton, which encloses the whole, cause errors due to selective absorption. On account of this fact correction factors must be used for different wave lengths. These will be discussed in Chapter IV on relative dosage. For practical dosage it is of importance to use an instrument which is not subject to errors due to varying hardness, or, still better, one which has the same hardness factor as the biologic object—the tissues or the skin. The biologic object absorbs hard and soft rays very differently; if there is an instrument which reacts in the same way to various hardnesses, then a close relation ought to exist between the readings of this instrument and the biologic reaction. Now there are substances which can be used for this purpose. First of these is, of course, the biologic specimen itself. The great significance of the experiments of Juengling on beans, those of Wood on mouse tumors, and those of Kroenig and Friedrich on frog larvae, lie in the avoidance of the error due to hardness. Hence these methods are to be recommended for comparing the biologic effect of rays of different hardness. These methods have the advantage that systematic errors are absolutely excluded;

however, the disadvantage that they lack the accuracy and convenience of the physical methods.

Another substance which can be used for measurements and which does not show any serious errors due to hardness, is air. Air consists of elements of atomic numbers 7 (nitrogen), 8 (oxygen), 1 (hydrogen), etc. Hence it has almost the same average atomic number as body tissue, whose average atomic number lies between 7 and 8. For this reason air and tissue show about the same hardness factor; the absorption of hard and soft rays takes place in about the same ratio in the two substances. This behavior of air is important since air serves as the active agent in ionization chambers. As far as the absorption of Roentgen rays is concerned, the effect in air is proportional to that in tissue. However, there are a number of factors which may lead to errors. First of all, the total amount of absorbed energy is not converted into ions but only a fractional part, which varies with the wave length and which is not definitely known. Further, the ions produced have different ranges. While in the tissues, with both hard and soft rays, dissociation takes place only at the point where the energy is absorbed, in air the secondary ions produce additional ions at various distances, depending on the wave length. Again, the Roentgen rays on entering and leaving the chamber excite characteristic radiation on the walls of the chamber. All these factors combined cause the ratio of ionizing to biologic effect to vary with the hardness. However, Holthusen has succeeded in controlling this hardness factor by calculation and Friedrich has constructed a small chamber of horn which has been experimentally so adjusted that it practically obviates the error due to hardness, at least over a definite

range of wave lengths. The readings obtained with such a chamber are valid, therefore, for various degrees of hardness.

The absorption also depends on the physical properties of the absorbing substance. The density and atomic number are determining factors. The value of the absorption coefficient is directly proportional to the density and inversely proportional to the third power of the atomic number. For this reason the true absorption increases very rapidly with the atomic number.

The table below gives the atomic number, the density, the true absorption coefficient, and the ratio of absorption at the wave length 0.2 A U for a few elements of interest. These values are calculated according to the formulas:

$\alpha = 0.0195\ N^{2.58}\ d \cdot \lambda^{2.8}$ for wave lengths below this point of discontinuity of the absorption curve; and

$\alpha = 0.0004\ N^{3.14}\ d \cdot \lambda^{2.8}$ for wave lengths above this point.

The second formula need only be used in the case of lead.

Element	Atomic number	Density	Wave length	μ	Ratio		
Water	(7.6)	1.0	0.2 A U	0.041	1		
Aluminum	13	2.6	0.2 A U	0.3	8	1	
Copper	29	8.9	0.2 A U	10.6		35	1
Zinc	30	7.1	0.2 A U	9.7			0.9
Lead	82	11.4	0.2 A U	41.			3.8
Lead	82	11.4	0.1 A U	60.			

The table shows that the true absorption of aluminum is about eight times as great as that of water; and that of copper thirty-five times as great as that of aluminum. Zinc absorbs about 10% less than copper and lead absorbs

the wave length 0.2 A U less than it does the harder wave length 0.1 A U, because the point of selective absorption lies between.

In practice we never deal with true absorption alone; the absorption due to scattering is always included. For this reason the values given in the above table are only preliminary and will be replaced by others later.

The coefficient of scattering depends on the density of the scattering substance and on the wave length of the radiation. The coefficient of scattering is directly proportional to the density. For this reason the value $\frac{\sigma}{d}$ is often given, which is independent of the absorbing material. It is designated as the mass absorption coefficient. It does not depend on the atomic number. The exact relation between it and the wave length is not known. It changes only little with the wave length compared to the true absorption coefficient. This is shown by the values of $\frac{\sigma}{d}$ found by various investigators and given in the table below:

Author	$\frac{\sigma}{d}$	λ	Elements
Barkla	0.20 A U	0.3-0.5 A U	Light elements
Hull and Rice	0.12 A U		Al, Cu, Pb.
Dessauer and Vierheller	>0.074 A U	0.19 A U	Water
Ishino	0.04 A U	0.12 A U	Al
Neukirchen	0.04 A U	γ	Water, Al, Glycerin, Turpentine

For water $\frac{\sigma}{d} = \sigma$, since the density of water is equal to unity.

Compared to $\bar{\mu}$, σ changes little with the wave length. Hence for soft rays σ becomes negligible in comparison with σ and the total absorption is practically determined by $\bar{\mu}$ alone. This is particularly true of the heavy elements, filter and diaphragm materials, since the true absorption increases with both the atomic weight and the density while the scattering is proportional only to the density. For these metals the scattering can, in general, be neglected.

The reverse is true for very hard rays. The true absorption can here become less than the scattering so that the latter becomes the primary factor in determining the total absorption. This is particularly true of the substances composed of elements of low atomic number, for example: water, air, and tissue. These substances scatter more than they absorb. Their behavior is determined almost wholly by σ.

Since the total absorption depends on the sum of $\bar{\mu}$ and σ, the preliminary values given in the table on page 135 must be replaced by more correct ones:

The ratio of true absorption of water and of aluminum was found to be about 1 : 8.

The coefficients of scattering are in the same ratio as the densities namely, 1 : 2.7.

Since in the case of soft rays the true absorption is the determining factor, we find that the two substances absorb soft rays in the ratio 1 : 8.

On the other hand with very hard rays, the γ rays of radium, for example, the ratio is determined by the scattering alone and is approximately as 1 : 2.7.

For intermediate wave lengths the ratio of absorption of the two substances varies continuously from the one extreme to the other. The following table give the exact values:

Hardness	μ Aluminum	μ Water	Ratio
Soft	5.6	0.7	8
Middle hard	1.08	0.21	5.1
Hard	0.52	0.17	3.0
γ rays	0.115	0.043	2.7

Hence we cannot speak of a univalent ratio between the absorption of water and that of aluminum. This ratio varies and must be determined for every mixture of rays.

The situation is the same with aluminum and copper. With 200 K V,

0.5 millimeters of copper corresponds to 12 millimeters of aluminum;

1.0 millimeters of copper corresponds to 22 millimeters of aluminum.

For 130 K V the following table applies:

Cu filter	Al filter	Ratio
0.1 mm	3.0 mm	30
0.2 mm	5.5 mm	28
0.3 mm	7.8 mm	26
0.4 mm	10.0 mm	25
0.5 mm	12.0 mm	24

Copper filters the soft rays about 29 or 30 times as strongly as aluminum; while it absorbs the hard rays only about 22 times as strongly. With copper, therefore, a better filter action is attained. This has already

been mentioned in the discussion of the intensity curves of Duane (see Figure 21). The explanation of the general trend of these curves will now be evident.

The values given for other substances are also modified by the scattering. The table below gives the total absorption coefficient and the half value layer for a radiation which is obtained with 200 K V, 1 millimeter of copper plus 1 millimeter of aluminum. The ratio of the absorption of various metals is also given:

Material	μ	Half value layer	Ratios		
Water	.17	4.1 cm	1		
Al	.52	1.3 cm	3	1	
Cu	6.0	0.12 cm		12	1
Zn	5.5	0.13 cm		11	0.9
Pb	30.	0.023 cm		[illegible]	5
Connective tissue	.168	4.1 cm	1.00		
Fat tissue	.152	4.6 cm	0.90		
Bones	.181	3.9 cm	1.08		

In this case the ratio of aluminum to copper absorption is found to be 1 : 12 compared to 1 : 22 as given before. The reason for this is that with the radiation used above the soft rays have already been filtered out by the regular filters (1 millimeter copper plus 1 millimeter aluminum) before the mixture is examined; while in the preceding instance the unfiltered radiation was examined directly.

The table shows, in addition, the close agreement between the absorption of water and that of the tissues. This should be the case also theoretically since not only is the density of the two substances the same but also

the average atomic weight, inasmuch as the tissues are composed of elements of low atomic numbers, namely, between 7 and 8. The deviations observed with bony and fat tissue are in opposite directions and will in general offset each other. Air spaces can decrease the total absorption by about 15%.

Experimental comparisons of the absorption of various tissues have been made by Nick and Schlager. The following table gives the values reported by these authors for hard rays; the absorption of water is arbitrarily set equal to 100.

Tissue	Absorption	Density
Water	100	1.00
Fat tissue	53 ?	.97
Blood serum	103	1.03
Brain	107	1.04
Muscles	100	1.05
Lungs	86	1.05 ?
Heart muscle	106	1.05
Kidney	106	1.05
Liver	107	1.06
Spleen	112	1.06

The table shows that only slight deviations from the mean and from the value obtained with water occur. The low value for fat tissue is probably incorrect; it is contradicted by measurements made by the author and would not be expected from the density and composition of fat tissue. The density of the tissues of the lungs appears to the author to be too high.

The next table compares a series of substances with regard to absorption. The figures give the percentage of radiation passing through layers of various thick-

nesses, provided the distance between the ionization chamber and the Roentgen ray tube is not changed. The measurements were made with 200 K V, 1 millimeter of copper plus 1 millimeter of aluminum and were carried out with an iontoquantimeter.

Material	1 cm	2 cm	5 cm	10 cm	15 cm	20 cm
	%	%	%	%	%	%
Water	92	85	68	45	30	20
Oak	94	88	74	55		
Ebony	90	82	61	37		
Balsa	98	96	92	84		
Brickstone	74-76	56-58	24-25	6-8	1.3	0.3
Concrete	72-75	50-54	17-23	3-5	0.5	0.2

Nearly all woods absorb less than water, but only slightly less. The absorption corresponds fairly well to the density. Ebony is the only one heavier than water; for this reason it also absorbs more than water. By gluing together equal thicknesses of ebonite and oak a very good wood phantom of bodily tissue can be produced. Wood is often used for mechanical support when the patient is treated from below on a mattress. Most woods are unsuitable for this purpose since they absorb too heavily (10-12%); balsa wood is a good material for this purpose as its absorption is hardly appreciable. A thickness of 2-3 centimeters must be used. An aluminum filter is, of course, superfluous in this case since the wood absorbs the secondary rays of the copper. Balsa wood is also used as a holder for radium preparations. It can easily be carved into any form and used to maintain a definite distance between the radium and the skin without absorbing the hard γ rays appreciably. The values given for brick and concrete show that very thick walls

are necessary to absorb all the radiation. About 1% of the incident radiation passes through a 15 centimeter (6 inch) wall. For the protection of the operator an absorption of 99% is not sufficient; the transmitted radiation should be reduced to 1/1000 or less. Hence lead covering is necessary.

The author has made a series of measurements on the ordinary protective materials with various transformers, voltages and filtrations.

For 190-210 K V and $^3/_4$-$^4/_4$ millimeter of copper the values given in the following table apply; these values give the intensity in percent of the intensity which would exist if the protective material were not present.

Material	1 mm	2 mm	3 mm	5 mm	10 mm	20 mm
Lead	7-10%	½-1%	1-2‰	1‰		
Lead glass			30-35%	15-20%	2-4%	1-2‰
Lead rubber	40-50%	20-25%	7-10%	3-5%	½-1%	

With the help of this table one can determine the amount of protective material required. Special precautions should be taken with rooms in which there are employes. Only 1/1000 or less of the incident radiation must be allowed to pass through the walls. For this reason walls of considerable thickness should be covered with 1½ or 2 millimeters of lead; wooden walls should be covered with 3-4 millimeters. A thickness greater than 5 millimeters of lead is unnecessary with the radiations used at present. The lead glass used for the small window which gives the operator a view of the treatmeant room need not be as heavy since the aperture allows only a small beam to pass through. A thickness of 10 millimeters is sufficient; more than 15 millimeters is overdoing protection; with large windows, which

might expose part of the operator's body to the radiation, a thickness of 20 millimeters should be used in order not to allow a penetration of more than 1/1000. For the protection of the patient during the relatively short exposure time a protective material which allows less than 3% to pass through is sufficient. For this purpose a thickness of some 2 millimeters sheet lead or 5 millimeters of leaded rubber is ample. Metallic lead should not be placed directly on the skin on account of the secondary radiation. With even an insufficient thickness of protective material there is little danger of harming the skin; however, a relatively large energy would be supplied to the total volume of the body and this would unnecessarily aggravate the ray sickness.

The values given above will enable an approximate solution of any problem involving protection; more exact calculations are hardly possible on account of the many complications which occur in any specific case.

A few general remarks may not be out of place.

According to Halberstadter every Coolidge tube sends out in the reverse direction a radiation which is softer than that proceeding in the forward direction (that of the central ray) and the intensity of which is about 1/7 that in the forward direction.

Every object struck by radiation scatters rays of practically the same hardness as the incident radiation and further emits softer (characteristic) radiation.

If not protected against this stray radiation, the total surface of the patient receives an amount of energy equal approximately to 1/30 of that applied at the port of entry. If an erythema dose is denoted by 100%, the total surface of the patient receives 3%. The patient should be protected against this stray radiation not because of

its effect on the skin, but because of the effect on the general reaction of the patient.

The patient being treated also scatters radiation; the order of magnitude of the latter with a large port of entry, is approximately 1/10 of the energy supplied to the region directly rayed.

At a distance of 50 centimeters to one side of the patient the intensity amounts to 1%. Hence the patient can, as a first approximation, be regarded as a source of radiation, the intensity of which is about 1/100 of that emitted by the Roentgen ray tube with filters. Against this radiation the operator must, of course, be protected.

In the consideration of protection against radium radiation a distinction must be made between the easily absorbed α, β, and soft γ rays, and the hard γ rays. Protection against the first group can be attained with strong absorbing materials: lead, barium-concrete, etc.; protection against the hard γ radiation is given only by distance.

The customary protective measures, namely, the handling of radium preparations with tweezers and the carrying of radium preparations in lead containers, are well known.

§2. Laws of Distribution.

We now come to the discussion of the distribution of the radiation.

Since the distribution depends on a number of factors, it is necessary to discuss these factors separately before taking up the actual distribution in a number of examples.

The distribution of the radiation is dependent on

(1) The law of inverse squares.

(2) The law of absorption.

(3) The scattering.

In the following we shall endeavor to synthesize the actual distribution from its components.

(1) The law of inverse squares enables us to calculate the distribution along the central ray if we temporarily ignore the absorption and the scattering. In Chapter II it has already been shown, that with increasing focus skin distance, the distribution at a depth becomes more favorable. Of course, in order to obtain the same surface energy the time of radiation must be increased by an amount which is easily calculated. Let us set the energy which the surface receives at all focal distances arbitrarily at 100; then the curves of Figure 30 give the intensities at various depths, on the basis of the inverse square law *alone*. The greater the distance, the greater the depth dose, and the better the distribution in the interior; however, with increasing distance the exposure time becomes more and more uneconomical. It has been found that in the treatment of malignancies 50 centimeters is the most practical focus skin distance, at least with the present apparatus.

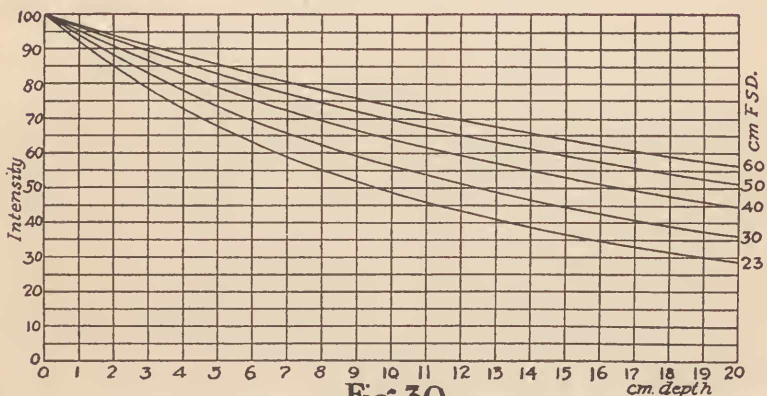


Fig. 30

Intensities at Various Depths for Various Focal Distances, According to the Inverse Square Law, Absorption Neglected.

If in the future the milliamperage should be increased to 30 milliamperes, the focus skin distance could be increased, since the time loss would no longer be of significance. An increase of the kilovoltage to 250 K V would increase both intensity and hardness. In this case also a small increase in focus skin distance would be appropriate. For some treatments which require less intensity in the interior a distance of 30 centimeters is appropriate.

In changing from one focal distance to another the following table can be utilized:

Focus skin distance	Time	Depth dose, per cent				
30 cm	36 (Min)	24	28	32	36	40
40 cm	64 (Min)	28	32	37	41	46
50 cm	**100 (Min)**	**30**	**35**	**40**	**45**	**50**
60 cm	144 (Min)	32	37	42	48	53
70 cm	198 (Min)	33	39	44	50	55

The last table, moreover, takes into account both absorption and scattering; without these, greater depth doses would be expected.

(2) The distribution resulting from total absorption when neither the law of inverse squares nor the scattering is taken into account, i.e., when the distance is very great and the port of entry very small, is given by the following law:

In every centimeter the same percentage of the incident radiation is absorbed (transformed and scattered). Figure 31 shows this very clearly for two different hardnesses.

The figure shows a series of important facts:

(a) The same percentage of the incident radiation is absorbed in each layer.

(b) The energy absorbed per centimeter, or better, per cubic centimeter, is therefore proportional to the transmitted intensity.

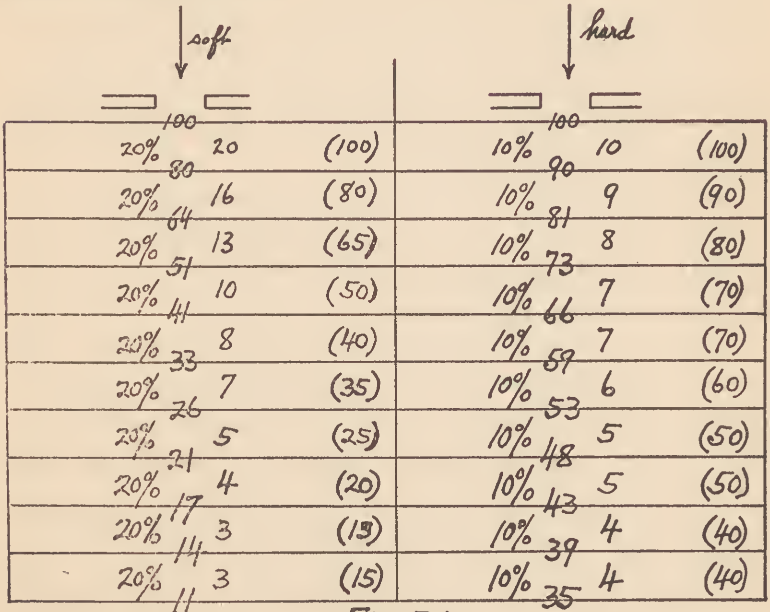


Fig. 31.

Depth Distribution of Applied and Absorbed Energy for Soft and Hard Rays.

(c) If two radiations of equal energy but of different hardness are applied, then the softer radiation is more strongly absorbed in the upper layers, and for this reason soft rays produce a greater biologic reaction near the surface.

(d) For the same absorbed energy in the surface layer, the energy absorbed at various depths decreases more rapidly with soft rays than it does with hard rays. Since the reaction of the skin and of malignant tumors is determined primarily by the absorbed energy, it is readily seen why the hard rays are more effective in deep therapy.

The foregoing considerations show that for rays of one and the same hardness it is immaterial whether the intensity or the absorbed energy is used for describing the depth distribution or predicting the biologic reaction. The same numerical result is obtained in either case. On the other hand, in comparing hard and soft radiations the absorbed energy must be used as the basis if a hardness error is to be avoided.

The data given in the tables can be made more comprehensive by means of curves. (Figure 32.)

The ordinates represent the intensities, the abscissa the depth within the tissues.

These curves are called exponential curves. They have the property that for equal distances along the abscissa the ordinates decrease by equal percentages. Such curves and all the preceding considerations apply only to homogeneous rays. In practice, however, a mixture of rays of different wave lengths, that is, a more or less unhomogeneous or heterogeneous beam is dealt with. On their way through the tissues heterogeneous beams lose their softer components more rapidly than they do their harder ones. The absorption at the beginning is therefore determined by all components, while at a depth it is determined primarily by the hard components. The absorption curve is no longer exponential; the absorption may at first be 18 per cent per centimeter while in the deeper layers it may be only 11 per cent. The curve of such a mixture is shown by the dotted line in Figure 32.

The heterogeneity is most accurately defined by the spectral composition of the beam. In practice a more convenient definition is, however, the ratio of the first two half value layers.

For homogeneous rays the half value layer does not change as the rays penetrate into the tissues. This is shown by Figure 32. The intensity of the hard radiation changes from 100 per cent to 50 per cent at a

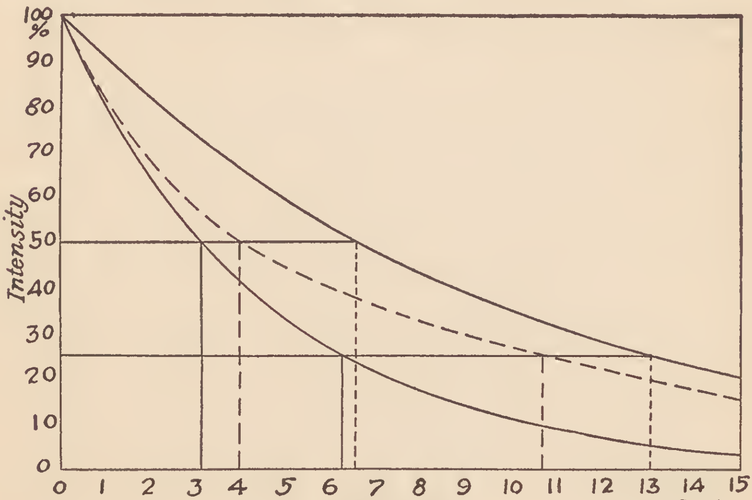


Fig 32

Intensity Curves and Half Value Layers of Hard and Soft Homogeneous Rays, and Mixed Unhomogeneous Rays.

depth of 6.5 centimeters. It is reduced from 50 per cent to 25 per cent in the next 6.5 centimeters. Hence the first two half value layers are equal. The quotient of the two is equal to one. The same holds for the soft radiation. For the unhomogeneous radiation (dotted curve of Figure 32), however, the first half value layer is 3.9 centimeters and the second 6.7 centimeters. If we divide one by the other we get

$$\frac{h_2}{h_1} = \frac{6.7}{3.9} = 1.7$$

This quotient is called the factor of heterogeneity. It is a measure of the heterogeneity of the radiation.

For homogeneous rays the factor is equal to 1.

In some text books a so-called point of homogeneity is mentioned. It is defined as the point at which the radiation ceases to be heterogeneous and becomes homogeneous. Such a point exists neither theoretically nor experimentally.

In the above absorption curves the law of inverse squares, which has been discussed in the preceding chapter, was not taken into account. A combination of the two curves can be effected by multiplying together corresponding values, reducing the first product to 100 by dividing by the proper number, and reducing all the other products in the same ratio. As an example the 50 cm focus skin distance curve is combined with the curve representing the homogeneous hard radiation ($\mu = 0.167$; $h = 4.2$ cm) as follows:

0 centimeter	100 × 100	10000 reduced to 100
2 centimeters	73 × 93	6800 reduced to 68
5 centimeters	44 × 83	3650 reduced to 36
10 centimeters	19 × 69	1310 reduced to 13
20 centimeters	4 × 51	204 reduced to 2

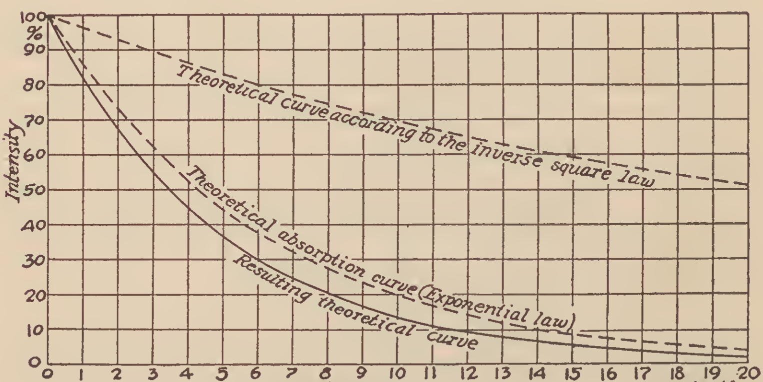


Fig 33

Calculated Intensity Curves.

Figure 33 shows the resulting values as an intensity curve for very small fields (pencils of rays); this calculated curve agrees very closely with the results of actual measurements.

(3) However, the larger the size of field the more does the scattered radiation increase the values in the interior of the rayed volume. From the interior a part of the scattered radiation penetrates the region not rayed directly and a part is also scattered back to the surface of entry. The theory of scattered radiation is not yet sufficiently developed to enable an exact calculation of the scattered component. Moreover, there are still uncertainties in the experimental determination of this quantity; so far it has been assumed that the scattered radiation has the same hardness as the primary radiation. Recent measurements by Compton show, however, that the scattered radiation contains softer components besides.

Exact measurements have shown that the scattered radiation increases the intensity at the surface as follows: (200 K V, 1 mm copper)

With (0 centimeter $)^2$ P of E, about 0%
With (5 centimeters$)^2$ P of E, about +16%
With (10 centimeters$)^2$ P of E, about +30%
With (15 centimeters$)^2$ P of E, about +42%
With (20 centimeters$)^2$ P of E, about +50%
With (25 centimeters$)^2$ P of E, about +52%

With small ports of entry the scattered component increases very rapidly with an increase in size of field. With large ports of entry it approaches a maximum, which corresponds to the greatest amount of energy scattered back. In the interior this increase of energy, due to the addition of scattered radiation, is still greater.

The farther an element of volume is within a rayed medium, the greater is the amount of scattered radiation which it receives. The added component due to scattering may amount to several hundred per cent of the primary energy. According to measurements made by the author with the radiatio nin vogue at present (200 K V, 1 millimeter Cu., 50 centimeters focus skin distance, large port of entry) it amounts:

At the surface to 50 per cent.
At the depth of 5 cm to 200 per cent.
At the depth of 10 cm to 350 per cent.
At the depth of 15 cm to 500 per cent.
At the depth of 20 cm to 700 per cent.

On this account the values given by the preceding curves must all be considerably increased. If for the sake of comparison the intensity at the surface is again taken as 100 per cent, and all values reduced in the same ratio, a curve results which deviates considerably from those discussed so far. (Figure 34.)

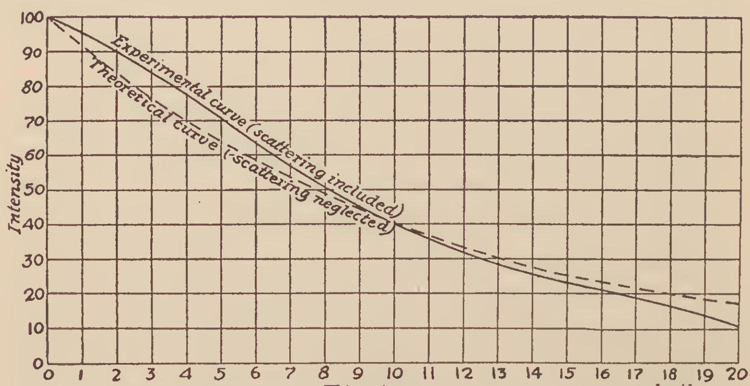


Fig. 34

Calculated and Observed Intensity Curves.

At the beginning it decreases less rapidly than was calculated from the inverse square law and the absorp-

tion law (Figure 33) under the assumption of the same intensity at a depth of 10 centimeters. Also farther along small discrepancies between the curves are observed, for example, if the total depth is decreased so that the radiation emerges again after penetrating 15 centimeters, the intensity in the last few layers decreases considerably. At the point of emergence it will be about one-fifth less than it was before. In general, it may be stated that by the removal of the overlying tissue, the intensity at any given point on the surface of emergence is decreased by about 20 per cent.

§3. Distribution Curves, Distribution Charts.

After these general considerations we may give the depth distribution for a series of treatment factors used at present.

The customary factors used in deep therapy when a 200-280 K V transformer is available, are the following:

190 to 210 K V,

½ to 1 millimeter copper plus 1 millimeter aluminum,

50 centimeters focus skin distance.

With large ports of entry, 20 centimeters × 20 centimeters, or 22 centimeters diameter, the depth dose (at a depth of 10 centimeters) is 40 per cent; it can vary between 39 and 42 per cent. If smaller fields are used the depth dose decreases correspondingly. The following figure (35) gives the distribution of intensity along the central ray for the above conditions.

The exact shape of the curves depends somewhat on the transformer, rectifier, the exact voltage and the filter thickness. The curves shown in Figure 35 represent the average of a series of measurements with different transformers, 200 K V and ¾ millimeters copper. The curves agree very closely with those obtained by

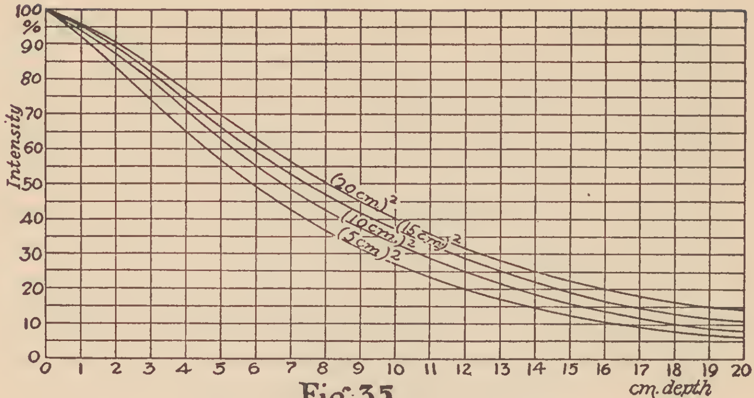


Fig 35

Experimental Intensity Curves.
200 KV Max.
¾ MM Cu.
50 CM F. S. D.
Various Sizes of Field.

Glasser in this country and Glocker and Friedrich in Germany, but deviate slightly at several points from those of Dessauer. These curves can be used for the

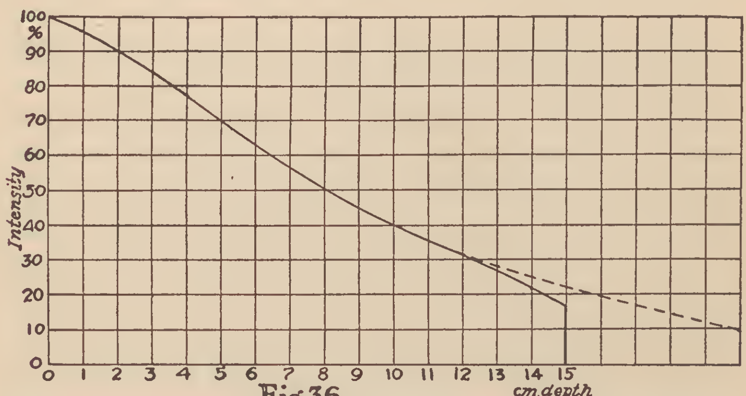


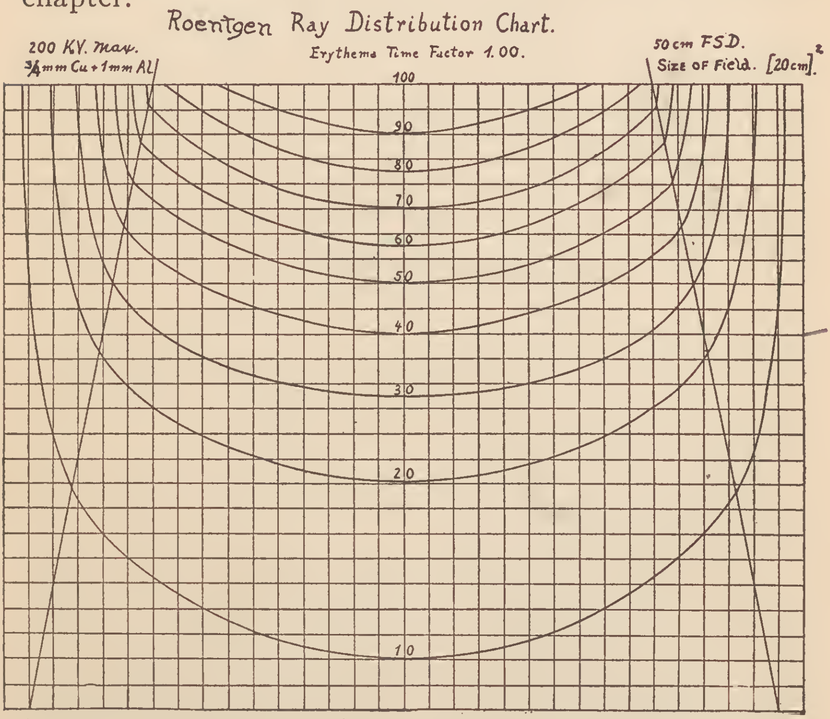
Fig. 36

Intensity Curve in Continuous and Discontinuous Medium:
200 KV.
¾ MM Cu.
50 CM F. S.D.
(20 CM)² Size of Field.

determination of the intensity along the central ray with a close approximation to the truth.

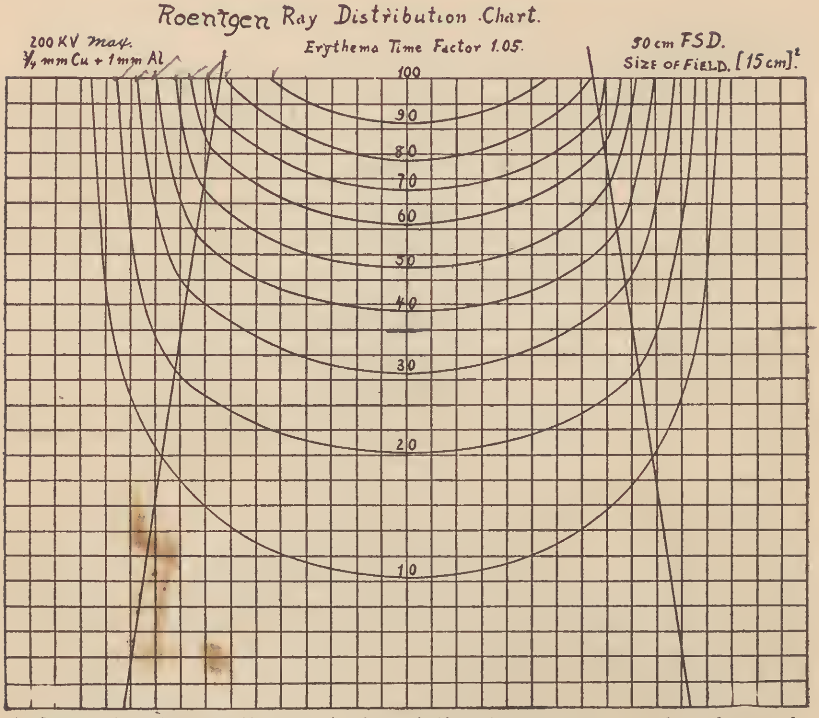
The curves give the intensity for all points which lie within the rayed medium. At points where the rays leave the medium, part of the scattered radiation is lacking; at these points the intensity is about one-fifth less than the values given. Hence the curve in the case of a thin patient assumes the form sketched in Figure 36.

Such curves are sufficient in many cases for practical dosage; they give a survey of the effect at various depths and serve as a guide in applying the desired energy. The details of their application will be described in the next chapter.



At boundaries of the medium, 20% of the indicated percentage must be substracted.

Fig. 37A. One-third Actual Size.



At boundaries of the medium, 20% of the indicated percentage must be substracted.

Fig. 37B. One-third Actual Size.

It is often desirable to know the exact distribution throughout the whole interior, outside of the central ray and outside of the directly rayed region. For this purpose the charts of Figure 37 are used.

These charts show, for the conditions given above, the following details:

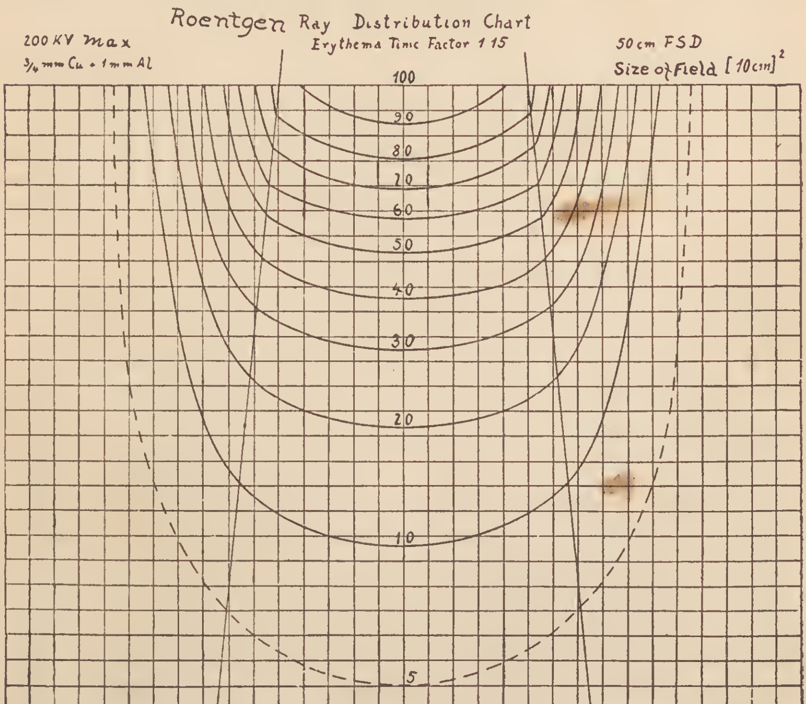
(a) The intensity distribution along the central ray.

(b) Isodosage lines, i.e., lines at all points of which the intensity is the same. The latter indicate the intensity in the remaining rayed and unrayed regions. At the boundary the change is discontinuous in the case of upper centimeters and continuous in the case of the deeper ones.

(c) The change of the required exposure time with change in size of field. It is assumed that the erythema exposure time is known for a field 20 centimeters × 20 centimeters. Then the erythema time factor gives the ratio in which the exposure time must be increased with a smaller field.

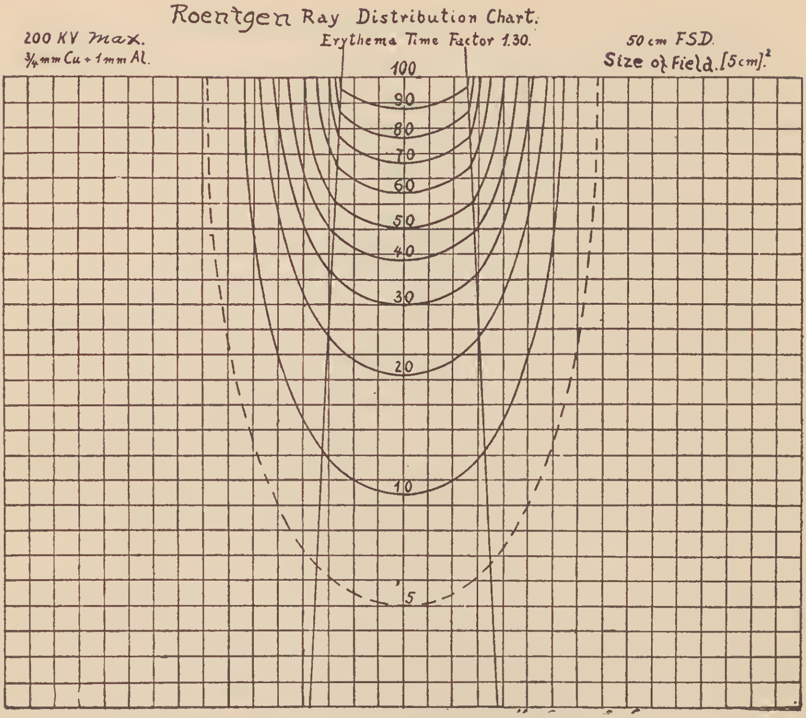
(d) The decrease of intensity at surfaces of emergence. This is due to a lack of scattered radiation.

A glance at the chart shows that with the large fields the intensity is distributed very uniformly around the central ray and that the scattered radiation affects the non-rayed region to a considerable extent. In the case of small fields this effect is very limited; the intensity falls off very rapidly outside the limits of the primary beam.



At boundaries of the medium, 20% of the indicated percentage must be substracted.

Fig. 37C. One-third Actual Size.



At boundaries of the medium, 20% of the indicated percentage must be substracted.

Fig. 37D. One-third Actual Size.

These facts are important if in the one case it is desired to ray a very large region homogeneously and if in the other case it is desired to concentrate the radiation in a small region and protect the surrounding organs as much as possible.

Sometimes a transformer capable of delivering 200 K V is not available for deep therapy. With 140 K V peak value a filtration of one-half millimeter copper plus one millimeter aluminum is sufficient. The most favorable focus skin distance is again 50 centimeters. Under these conditions the radiation is less penetrating and less intense than with the conditions so far discussed. On

account of the smaller penetration more ports of entry are necessary; this, together with the diminished intensity increases the total treatment time enormously.

The following curves give the distribution under these conditions. The maximum intensity at 10 centimeters depth with large fields is about 35 per cent; for small fields it is correspondingly less. (Figure 38.)

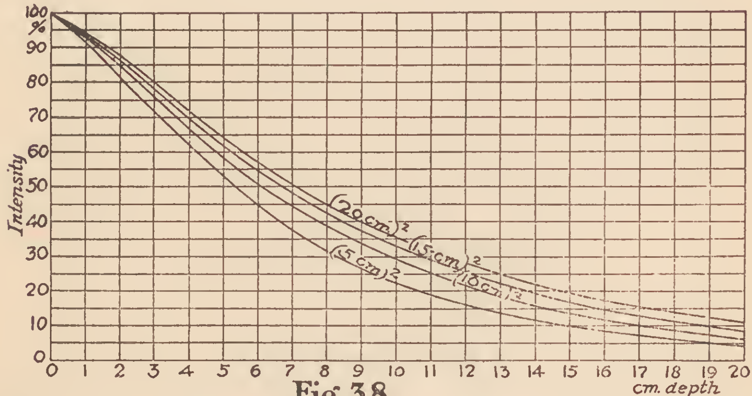


Fig. 38

Experimental Intensity Curves.
140 KV.
½ MM Cu.
50 CM F. S. D.
Various Sizes of Field.

In some cases, especially those involving non-malignancies, very penetrating rays are not necessary. The conditions can be 140 K V, 6 millimeters aluminum, 30 centimeters focus skin distance; large fields are generally not required. Figure 39 shows the distribution of the intensity for a field of 10 centimeters × 10 centimeters and one of 5 centimeters × 5 centimeters.

In contrast to these filtered rays, which are used in deep therapy, in the following the intensity distribution of a non-filtered radiation will be indicated. The radiation is produced with 100 K V (seven-inch gap), no

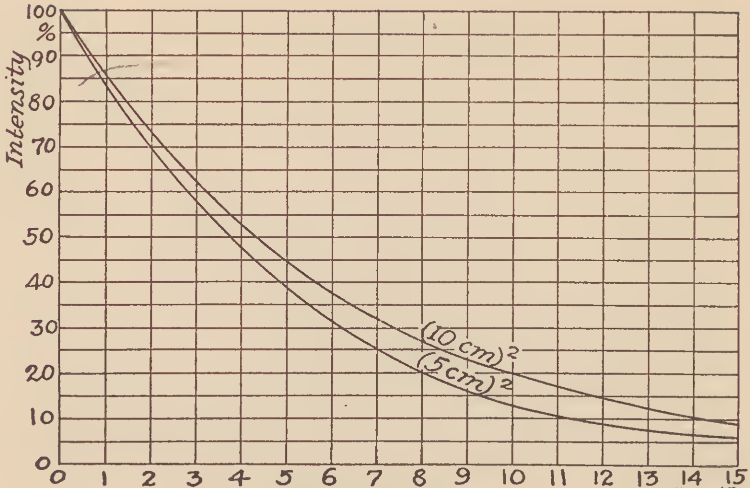


Fig. 39

Experimental Intensity Curves:
140 KV.
6 MM Al.
30 CM F. S. D.
Various Sizes of Field.

filtration, 20 centimeters focus skin distance. The depth dose can hardly be determined on account of its smallness and the inaccuracy in the measurement of such an unhomogeneous radiation. The half value layer is about one centimeter of water or tissue. The port of entry is a few centimeters square. (Figure 40.)

The curve shows that the intensity falls off very rapidly. Hence this radiation can be used only for superficial therapy when the object is to ray a surface growth (epithelioma) very intensely without greatly affecting the tissues underneath. In these cases of localized treatment, on account of the rapid decrease in intensity, a dose 2 to 3 times as heavy as in deep therapy can be given without injury.

With radium rays the situation is very much the same. The intensity decreases very rapidly on account

of the small distance between the preparation and the tissue rayed. The decrease due to absorption is almost negligible in comparison, while the component added by scattering is relatively large on account of the extreme hardness of the radiation. At large distances the intensity decreases inversely as the square of the distance; in the immediate neighborhood the intensity decreases inversely as the first power of the distance. All this applies only to strongly filtered radiation, when all

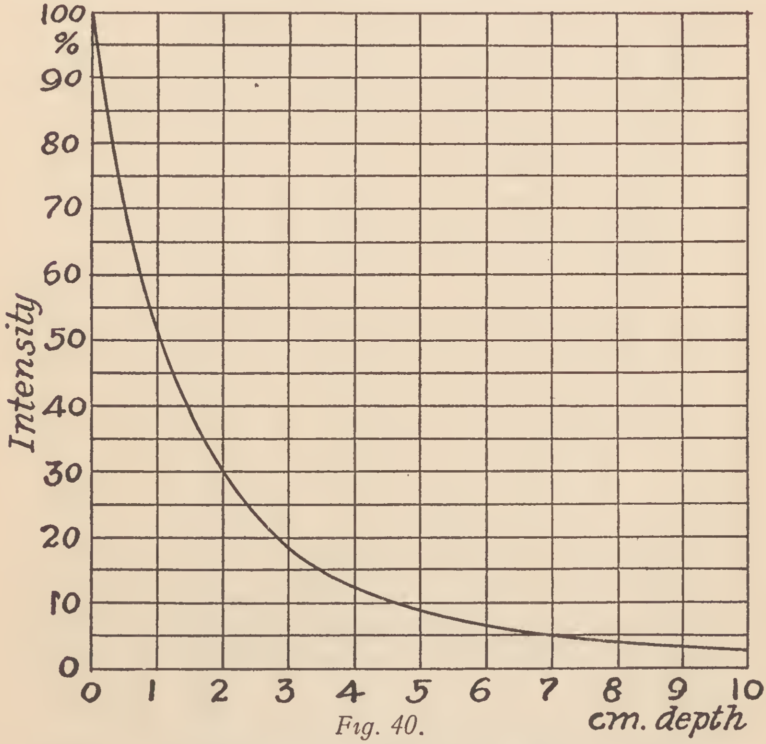


Fig. 40.

Experimental Intensity Curves:
100 KV.
No Filter
20 CM F. S. D.
Small Port of Entry.

beta rays and soft gamma rays are absorbed. If the filtration is not so heavy, the absorption curve of the soft rays is superposed and the distribution is still more unhomogeneous.

We have already seen that also with radium the depth distribution becomes better with an increase of distance and corresponding increase in exposure time.

In the following figure (41) the distribution obtained with a 50 milligram preparation filtered by means of a

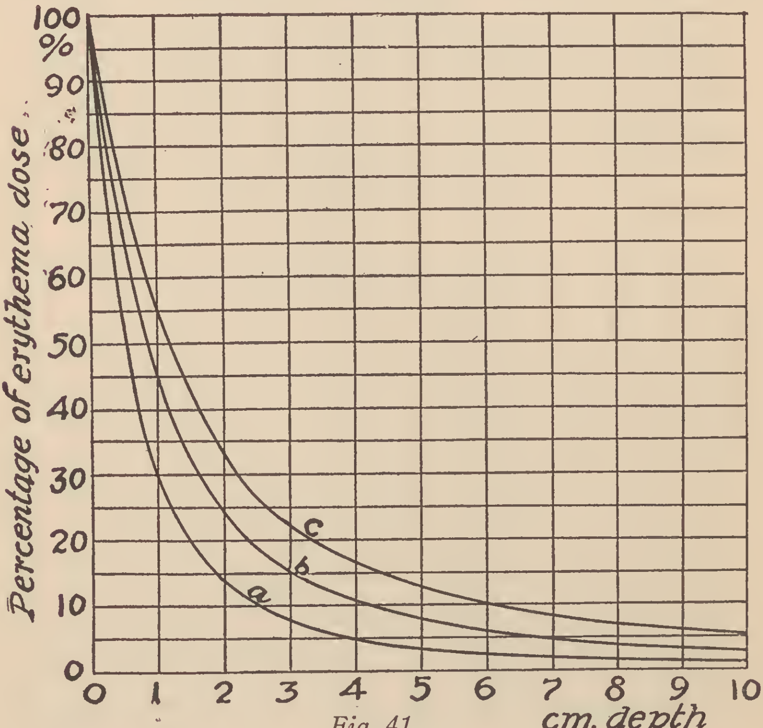


Fig. 41.

Distribution Curves of Radium Capsules in Human Tissue.
1.5 MM Brass Filter.
Erythema Dose Designated by 100.
a). 1 CM F. S. D., About 500 (250) Mg Hrs.
b). 2 CM F. S. D., About 1500 (750) Mg Hrs.
c). 3 CM F. S. D., About 2500 (1250) Mg Hrs.

small brass tube with 1.5 millimeter walls is given. The various curves represent different focus skin distances, measured from the center of the tube to the surface of the medium rayed.

The curves show, first, how very rapidly the intensity decreases in the first centimeters; and second, that it is extremely important to have a distance of 2 to 3 centimeters between the tube and the skin if a certain depth effect is to be produced. A comparison shows that the curve of the radium preparations corresponds very closely to that of the unfiltered Roentgen radiation (Figure 40) provided a focus skin distance of about 1.5 centimeters is chosen in case of the radium radiation. It is also well known that the biologic effect produced by the two radiations on the skin and on skin diseases is very similar in spite of the great difference in wave length between the two types.

For the purposes of radium dosage and combined radium and Roentgen treatment, it is important to know the energy which produces an erythema. If this energy is set equal to 100, it can be used as a standard with which the energies at other points can be compared.

Since also in Roentgen ray therapy the skin is given an erythema and since, further, on the Roentgen distribution charts this value has been set equal to 100, an addition of Roentgen and radium energies is possible without any further calculations. With the conditions given above, 50 milligrams of radium element, 1.5 millimeter brass and a thickness of 1.4 centimeters of tissue, paraffin, bakelite, or water interposed, about 20 hours are required to produce a strong erythema with blistering, while 10 hours produce a very mild reaction. If, therefore, 500-1000 milligram hours are applied, a point

at a distance of 1.4 centimeters from the preparation receives an energy, which, applied to the skin, would produce a strong or a mild erythema, respectively. Either one of these doses or any one between can at convenience be used as a unit and designated by 100.

In this way a biological scale is fixed, so to speak. If all intensity and energy values are referred to it, the isodosage lines*, which enable an estimation of the biologic effect without any further calculation, can be drawn.

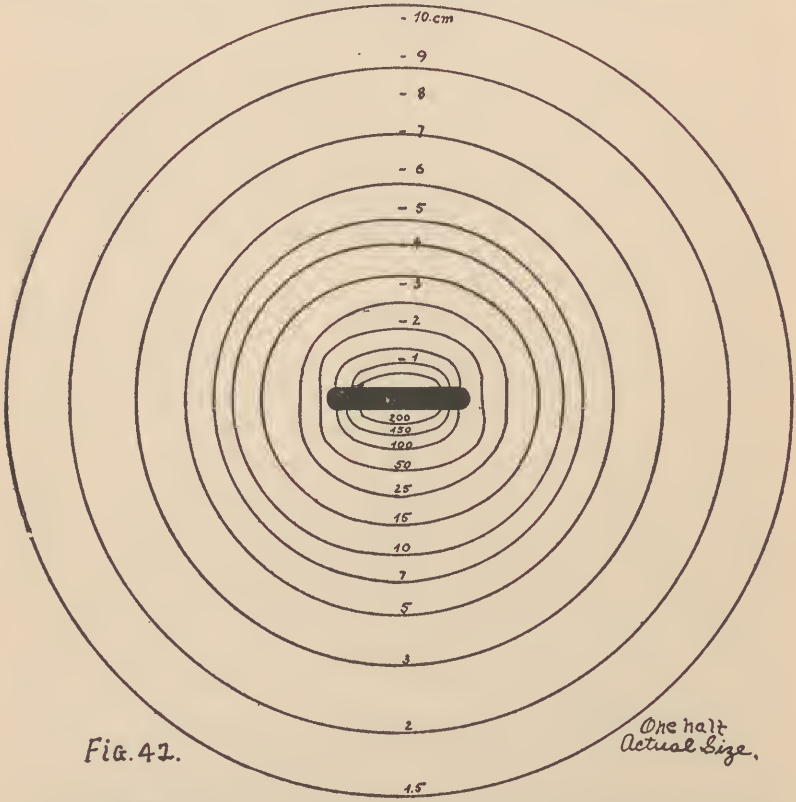


Fig. 42.

Distribution Chart of Radium Capsule, Surrounded by Tissue, 1.5 MM Brass Filtration, 1000 (500) Mg Hrs Applied Erythema Dose Designated by 100.

*Isodosage lines have been introduced by O. Glasser into radium dosages.

Figure 42 shows the radium isodosage lines for an application of 1000 (500) milligram hours. From this table it is easy to determine the effect of any number of milligram hours; for example, for 3000 (1500) milligram hours every value indicated must be multiplied by 3.

The detailed application of these curves will be taken up in the following chapter.

The distribution in a plane perpendicular to the axis of the needle obtained with a radium needle is given in Figure 43.

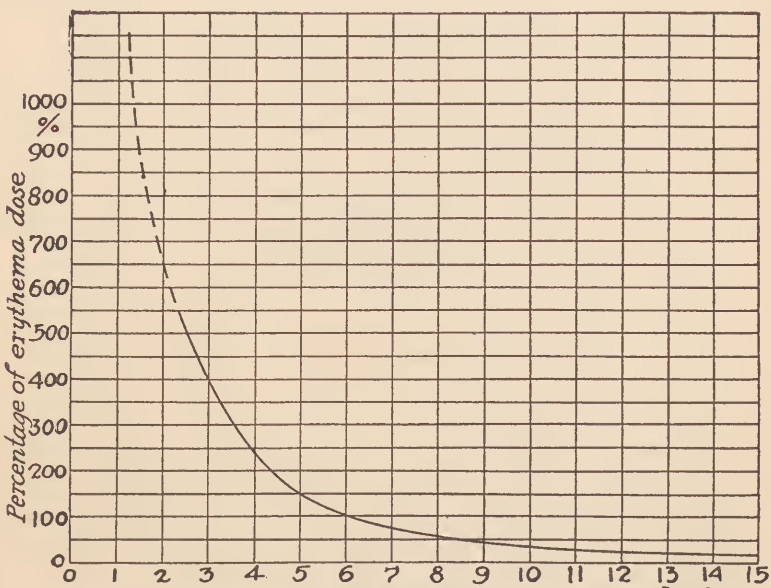


Fig 43

Distribution Curve of Radium Needle in Human Tissue.
100 (50) Mg Hrs Applied.
Erythema Dose Designated by 100.

The figure shows that the decrease is more rapid than in the preceding case on account of the weaker filtration. Here again the energy which produces an erythema is set equal to 100. The values refer to an application of

10 milligram $\times$ 10 hours, that is, 100 milligram hours, if a well defined erythema is to be produced. A mild erythema is attained with half of this dose. A simple calculation makes it possible to estimate the reaction for other stronger and weaker applications.

The isodosage lines are drawn in Figure 44.

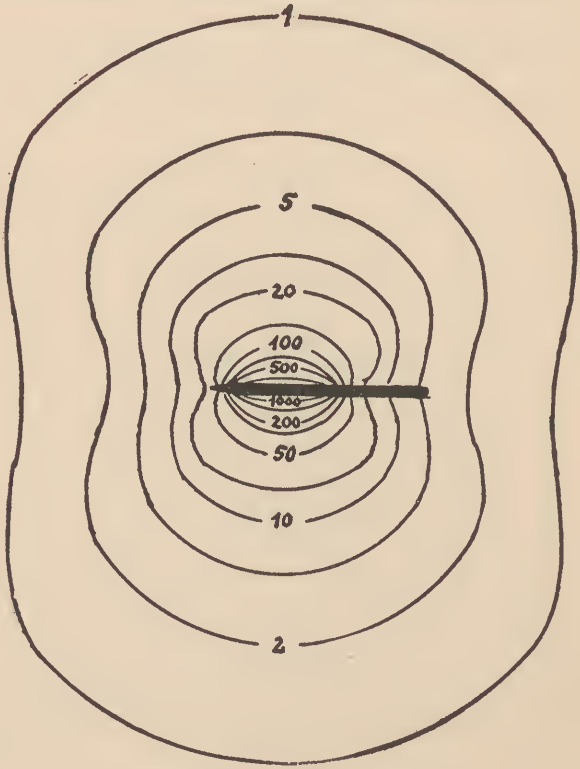


Fig. 44—Actual Size.

Distribution Chart of Radium Needle, Surrounded by Tissue.
100 (50) Mg Hrs Applied.
Erythema Dose Designated by 100.

The decrease is still more rapid in the case of surface applications where no filtration is used.

Figure 45 is a graphic representation for two cases: (a) without filtration, and (b) with 1 millimeter of copper.

In Figure 45a it is assumed that a full strength plaque of 1 square centimeter and 5 milligrams of radium element is applied for 12 minutes.

This is exactly 1 milligram hour and produces a definite erythema (100).

In Figure 45b with the same applicator and 1 milli-

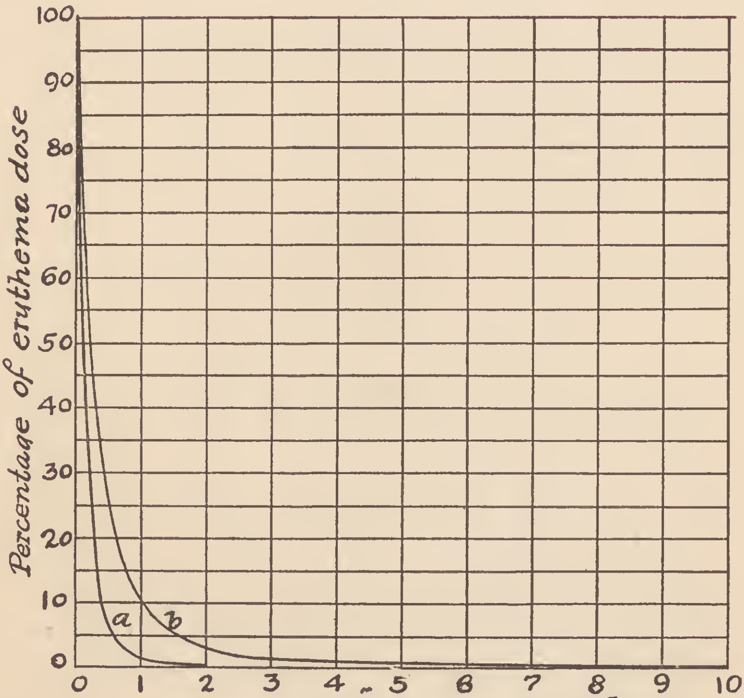


Fig. 45

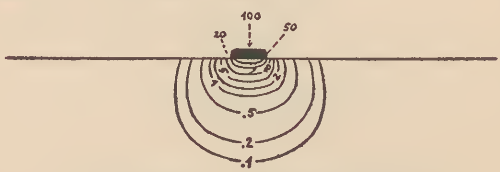
Distribution Curves of Radium Plaque in Human Tissue.
a). No Filtration, 0.5 (0.25) Mg Hrs Applied. } *1 CM.*²
b). 1 MM Cu. Filtration, 100 (50) Mg Hrs. Applied }
Erythema Dose Designated by 100.

meter Cu, 20 hours, that is, 100 milligram hours are required to produce a well defined erythema (100).

Half this amount of energy produces a very mild reaction which corresponds approximately to the epilation dose produced with Roentgen rays. (0.5 milligram hours and 50 milligram hours.)

Figure 46 gives the isodosage lines and shows the distribution in the interior.

Such intensity curves or isodosage charts can be used to advantage in determining both the intensity distribution resulting from a single application and from a combination of several preparations. Hence they can also be used for determining the exposure time required to produce various desired reactions.



No Filtration, 0.5(0.25) Mg Hrs.

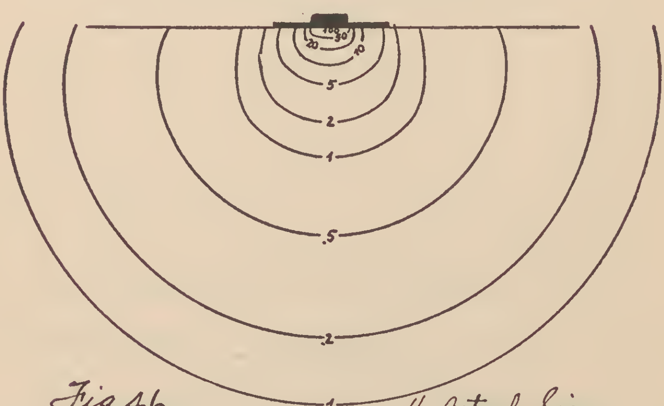


Fig. 46. ½ Actual Size.

1 MM Cu. Filtration, 100 (50) Mg Hrs Applied;

Distribution Chart of Radium Plaque; Erythema Dose Designated by 100.

This will be illustrated by examples in the next and the last chapter.

An interesting comparison of the penetration of Roentgen rays and of radium rays has been made by Gaylord and Stenstrom. The depth doses measured in a water phantom under various experimental conditions are given in the table below:

Radiation	X rays, 200 K V	Radium Rays
Radiation surface	$(0.2\ \mathrm{cm})^2$	$0.1\ \mathrm{cm}^2$, $\frac{3}{4}\ \mathrm{cm}^2$, $6.5\times 7\ \mathrm{cm}^2$
Filter	0.5 mm Cu + 2 mm paper	2 mm brass + 2 mm rubber
Focus skin distance	20 cm	20 cm
Size of field	13.5 cm	$25\times 25\ \mathrm{cm}^2$
Depth dose	24%	26%, 30%, 34%

The table shows that under the conditions of the experiments radium radiation is very superior to Roentgen radiation. However, several points must be noted: first, the filter thickness used in the case of the Roentgen radiation is very small; second, the focus skin distance used in the case of the Roentgen radiation is much less than would ordinarily be used in deep therapy; thirdly, the focus skin distance, namely 20 cm, used in the radium experiments would mean a very inefficient radiation and would require an enormous quantity of radium; and, fourth, the port of entry is extremely large. For practical purposes, therefore, Roentgen treatment at the present time is far superior to radium treatment.

In concluding the subject of absorption it might be well to discuss what happens to the absorbed energy.

1. We have already seen that part of the incident rays are scattered. According to older conceptions this process occurred without any change in wave length; however, according to recent experiments by Compton, the wave length is slightly increased. The increase is a function of the degree of deflection, but is independent

of the quality of the primary radiation and almost independent of the physical and chemical properties of the scattering medium.

2. Just as the tungsten anticathode and filtering media give off characteristic radiation when irradiated, so the irradiated tissues also give off characteristic radiation. The characteristic radiation of the constituent elements of the tissue, H, C, N, O, etc., is extremely soft, the K radiation of carbon, for example, has a wave length of 42 A U. These soft characteristic radiations are produced both by hard and soft Roentgen rays, as well as by the β and γ rays of radium. They are absorbed in close proximity to their origin and are transformed further.

3. The absorption of all the rays which penetrate the tissues results in the production of electrons, similar to the β rays of radium or the cathode rays of the Roentgen tube. The velocity and range of these so-called secondary β rays is a function of the hardness of the Roentgen or γ rays which produce them. The absorption of these rays goes on by degrees and results in the production of tertiary rays of lower velocity.

It can readily be seen from the above that the transformation of rays in the tissues is very complicated. Rays with vastly different physical properties and of varying penetrability are superimposed. In the aggregate these rays are all designated as secondary rays.

The end result of all these transformations is a liberation of electrons from the constituent atoms of the tissues. That is, the atoms composing the biologic substances are split into positive and negative ions. In general the physical process of absorption of the rays in the tissues is just the reverse of what happens in the Roentgen ray tube when rays are being produced. While

in the gas tube and the Coolidge tube the velocity of the emitted electrons is increased by the potential difference, and these electrons in the form of primary β radiation bombard the anticathode producing X rays in the tissues, the X rays by reconversion into second cathode rays produce ionization. So we might say that the ionization in the Roentgen tube is transferred to the tissues by means of the X ray.

§4. Biologic Facts Regarding Quality and Intensity Distribution.

The question whether the biologic effects of hard and of soft rays are different and in what way they are different has been often raised and investigated both experimentally and theoretically. The answer to this question is not only very interesting from the theoretical standpoint, but also extremely important for the practical development of deep therapy. The latter continually demands more penetrating rays in order to produce a high concentration of energy in the regions to be rayed and at the same time protect the skin and the tissue through which the radiation passes. If qualitatively and quantitatively hard rays have the same or better properties than soft rays, this demand is justified, since it has been shown both theoretically and experimentally that hard rays do produce a more favorable energy distribution in the interior than the soft rays. If, however, the hard rays have unfavorable properties of any kind, their superiority over soft rays must at least be questioned.

Why should various hard rays produce different effects if the raying is carried out with equal intensities and exposure times?

One answer to this question can be obtained by analyzing an error which is made in the practical determina-

tion of intensity. With most measuring instruments we do not measure intensities at all but absorbed, or still better, transformed energies. We have already noted the discontinuity which appears in the region of the silver absorption band on a photograph of a spectrum. In this region the change in absorption brings to mind very forcibly the hardness error in intensity and energy measurements. However, this error is present throughout the entire spectrum: the absorption is different for different wave lengths. It increases from low values in the case of hard rays to greater and greater values in the neighborhood of the absorption band. Accordingly, the softer the radiation, the greater the fraction of the incident energy absorbed or transformed. On account of this fact, the amount of hard radiation is measured too low. This simple and frequently used method of measuring intensity by the photographic method is therefore fraught with a hardness error. This error could be eliminated in two ways: (1) experimentally by the use of a layer of such a thickness that all radiation is completely absorbed; (2) by the calculation of the total energy from the absorbed energy, if the relation between the two were known as a function of the wave length. Neither of these methods is practical.

Similar, but numerically different hardness errors occur in all other methods of measurement. Also in the case of the ionization of air in both small and large chambers only a small fraction of the radiation is absorbed, and this fraction varies with the hardness. The hard rays therefore again are measured too low. In this case the error of hardness can be practically eliminated by the use of a very large chamber, which contains a gas of particularly strong absorption, for example, methyl iodide

(CH_3I) which absorbs about 100 times as much as air. This method has often been used for comparing the intensities of hard and soft radiation without errors due to hardness.

If, now, with this correction, equal energies of hard and soft radiations are applied, it is found that the skin reacts more strongly to the soft rays. This is partly explained by the fact that the soft rays are more strongly absorbed and hence a greater amount of energy is utilized for producing biologic reactions. The correctness of this explanation can be shown by making the absorbed energy the same in both cases by applying a commensurate amount of hard radiation. If this is done, the differences in biologic effects are partially obliterated.

The concept of the dose was introduced as a consequence of these considerations and experiments. A consideration of the dose, that is, the energy absorbed per cubic centimeter, enables a better comparison of hard and soft radiation than a consideration of surface energy, that is, the energy falling on a square centimeter of surface.

The problem of dosage is not, however, solved by a determination of the absorbed energy. The reason for this can be shown by the following experiments: Let two photographic films be rayed with blue and with red light and let the same energy be applied in both cases. Since a photographic film practically completely absorbs both energies the same degree of blackening is to be expected. Experiment shows, however, that blue light produces a much greater blackening (optical density). Thus, in spite of equal absorbed energies, we have different reactions. This phenomenon is explained by the theory that long waves (red) primarily affect the mole-

cule as a whole: i.e., they produce heat. Short waves, on the contrary, affect the constituents of the molecule, the atoms, or even the electrons, and for this reason produce chiefly chemical and ionization effects. Hence light rays of short wave length produce a greater degree of blackening in the photographic film than the rays of long wave lengths.

A similar phenomenon is encountered in the effect of rays of short wave length on the biologic object. The long electromagnetic waves (diathermic rays) the infra red rays (heat rays), and the red light rays produce thermal effects primarily. As the wave lengths grow shorter a stimulating effect begins to appear, which is mild in the violet region of the visible spectrum but becomes very pronounced in the ultra-violet region. In the case of Roentgen and radium rays the thermal effect is always negligible compared to the irritating effect. It was Dessauer who called attention to this peculiar property of Roentgen and radium radiation. Dessauer has shown that with a Roentgen radiation of the customary type, in producing an erythema, only about two gram calories are supplied to the tissues—this is a quantity of energy which would raise the temperature of the rayed region only about 1/1000 degree centigrade. That is, a hot application or a drink of hot water represents many times the quantity of energy, which with improper technique in the case of Roentgen therapy produces necrosis of the cells of the body and proves fatal. In order to explain this pronounced effect of Roentgen and radium rays on the biologic specimen, Dessauer assumes that the biologic reaction does not depend on the rise of temperature of the cells as a whole, since this rise is practically equal to zero, but depends on the local temperature rise

which occurs at the point of transformation of Roentgen and electronic energy. Although this "point heat" theory can be used to explain a few phenomena it appears rather uncertain in several ways. It does not explain the observed difference between the biologic effect of rays of various wave lengths. The process of absorption and the resulting action on the molecules immediately affected is the same. In both cases large local temperature rises will occur, followed by a small temperature rise of the whole neighborhood.

Next comes the question whether a rise in temperature occurs at all when Roentgen rays are absorbed. We have seen that the seat of their action is the interior of the atom, namely, the nucleus and the electrons. Accordingly, their effect is one of dissociation. A transformation into heat is feasible but not necessary and not proven. The secondary beta rays (electrons of high velocity) produced in the tissues are already products of the dissociating action of the Roentgen rays. These electrons strike other atoms and cause them to dissociate, similar to their ionizing effect in the case of gases.

If the original atoms and molecules reform, the absorbed energy, of course, can finally appear as heat energy, since it represents an increase in molecular motion. However, a chemical change can also appear as the final product. This may be a reduction of the cell substance and a dissociation of the cell. This assumption seems a great deal more suited to explain the poisonous effect of rays of short wave length as compared to the heating effect of those of longer wave lengths. This assumption is also closely connected with the well known chemical effects of rays of short wave length, for example, the effect on a photographic emulsion, on water, on

a chlorine solution of iodoform, on the barium platinocyanide tablet, and on many other substances. In particular it is a well known fact that solutions of starch and albumen are hydrolized by gamma rays; if pure albumen is rayed with radium, coagulation occurs.

Since the biologic reaction does not depend alone on the dose, that is, on the absorbed energy, as the wave length varies, there have recently been attempts to solve the question of what physical factors must be the same for various wave lengths in order to produce the same biologic reaction. The best experiments along this line are those conducted by Holthusen, who found it does not follow from the fact that the ionizing action of two beams of different wave lengths are the same that their biologic action is the same. For the same ionizing effect hard rays produce a weaker biologic reaction than soft rays.

Accordingly, in passing from hard to soft rays a smaller energy measured with the electroscope must be applied. The calibrated electroscope used by the author is calibrated for various degrees of hardness used in deep therapy.

The experiments of Holthusen have given the positive result that the biologic reaction of hard and soft rays is the same, if the energy of the secondary beta rays which they produce is the same. Since the relation between the energy of the secondary beta rays and the total number of ions produced is well known, it is possible to determine first the energy of the beta rays from the ionizing effect of the Roentgen rays and then deduce the biologic effect from the energy of the beta rays. In this way the dosage with beams of various wave lengths by means of "e units" is made possible. Calculations

made by the author give the number of "e units" required to produce an erythema for various degrees of hardness. The hardness is characterized by the kilo-voltage and filtration as well as by the effective wave length. The results are given in the following table:

Kilovolts peak value	Filter	λ Effective	Energy
100 K V	0.2 mm Cu	0.26 A U	1250 e
120 K V	0.4 mm Cu	0.23 A U	1400 e
140 K V	0.5 mm Cu	0.20 A U	1600 e
160 K V	0.6 mm Cu	0.18 A U	1720 e
180 K V	0.7 mm Cu	0.16 A U	1850 e
200 K V	0.8 mm Cu	0.15 A U	2000 e

On a knowledge of the relation between the ionizing effect and the biologic action is based Friedrich's method of dosage by means of a small chamber.

Friedrich has constructed a small chamber of such dimensions that the ionizing effect of hard rays is measured too small and, further, is measured approximately in the inverse ratio of the "e" values given in the above table. For this reason the measurements made with the Friedrich iontoquantimeter are not dependent on hardness—at least in the range of wave lengths used for deep therapy. The iontoquantimeter constructed by the author also avoids errors due to hardness in the range of wave lengths used in practice.

How the relation between the total energy of the Roentgen rays and the energy of the beta rays produced, varies with the hardness of the primary rays has not been definitely established. Holthusen found that for the same absorbed energy hard rays produce a greater beta ray energy than soft rays. Boos found the reverse.

From the viewpoint of physics Holthusen's results are more likely correct; namely: that as the wave length decreases the production of secondary beta rays increases.

In comparing the biologic effects of rays of various degrees of hardness, a further important consideration must be kept in mind, namely, the distribution of the energy. The well known fact that hard rays produce a better epilation with less irritation of the skin, is often cited to prove that hard and soft rays produce different biologic effects. The physical explanation is given by a consideration of the depth distribution. The hair follicles lie at a depth of several millimeters. The intensity of unfiltered rays decreases so rapidly in 1 or 2 millimeters that the necessary energy cannot be applied to the hair follicles without a strong over exposure of the skin and resultant erythema. With hard rays the difference in intensity is so small that an epilation can be produced with a very mild exposure of the skin. In medical literature the different action of rays of different wave length is often pointed out: as instances the action on the skin, skin diseases, epithelioma, nevi, etc., are cited. These examples, however, prove neither that hard and soft rays are specifically different nor that they are alike. In my opinion they really give information regarding the effect of different *distributions* of Roentgen or radium radiations. Under this head also belongs the observation that the reddening produced by the very soft unfiltered Roentgen radiation or beta radiation can be made to disappear by applying pressure; in case of hard rays (strongly filtered Roentgen radiation, γ radiation acting at a distance) pressure has no effect. The first effect is superficial, the second extends to some depth.

On account of the localized action of soft rays a

stronger reaction can be produced with less danger than with hard rays. In this connection it must be added that as far as distribution is concerned, radium rays belong in general to the class of weakly penetrating rays; we have already seen that their intensity decreases as rapidly in the interior as that of lightly filtered Roentgen rays.

In the light of the preceding considerations it is interesting to answer the following question:

(a) Why do diathermic rays and hard Roentgen rays produce such very different effects?

The absorption and distribution in the interior is approximately the same for the two types of rays but their physical action is very unlike; diathermic rays affect the molecular complex as a whole and therefore produce heating. Roentgen rays cause dissociation of the atoms and therefore change the structure of the atoms and molecules.

(b) Why do hard and soft Roentgen rays produce different effects?

Their action on the atomic constituents of the cells are approximately the same but the softer rays are much more strongly absorbed and therefore produce a much stronger local action.

(c) Why do lightly filtered Roentgen rays and hard radium rays act similarly?

Although the hardness is very unlike, the distribution resulting from absorption and the law of distance is so similar in both cases that the strongly localized superficial action (on epithelioma, etc.), is more prominent than the action at a depth.

(d) Why is the action of soft Roentgen rays and that of the beta rays of radium similar?

Although from the standpoint of physics we are deal-

ing with very different things: a wave motion and a corpuscular motion, still, in the interior both produce ions, and therefore have the same dissociating effect. The distribution produced in both cases by absorption and distance is also very much the same; it is very unhomogeneous. This explains the local effect of both types of rays.

The above statements may be summarized by the following general rule:

The biologic dissimilarity of rays which occupy very different positions in the scale of wave lengths is due chiefly to their different physical, chemical, and dissociative action; the biologic dissimilarity of rays which occupy positions close together in the scale of wave lengths is to be explained on the basis of their different distribution in the interior of a medium—whether the decrease of intensity is the result of absorption or of distance is immaterial.

Chapter IV

Practical Dosage

At the end of the preceding chapter we have touched on a series of questions regarding the biologic action of rays of different physical properties and the probable causes of this action. This subject is called "absolute dosage." The problems of "relative" or practical dosage are now to be considered.

The problem of practical dosage is to determine the correct dosage on the basis of the established physical principles with the help of the available measures and instruments.

In the following we will discuss the important points bearing on this subject.

§1. Installation of Roentgen Equipment.

One of the first questions is how the Roentgen apparatus is to be arranged. The most important points to be considered under this head are:

The accurate determination of focus skin distance;

The accurate determination of the center and boundaries of the field;

The accurate determination of the inclination of the central ray to the surface;

Maximum protection of the patient against electric shock, stray radiation, injurious gases and noise.

Maxiinum comfort of the patient.

The following arrangements are possible:

(a) The old tube holder with treatment cones for various focus skin distances and size of field. This

simple design is very convenient and enables very exact settings. The distance is determined by the length of the cone, and the size of field by the walls of the cone. All that needs to be known is the distance between the edge of the diaphragm and the outer surface of the cone. A separate determination of the center is not necessary in this case. This arrangement also has the advantage that the central ray can be set at any desired angle to the surface of the patient. The estimation and adjustment of the correct angle can be facilitated by marking the direction of the central ray on the lateral surface of the cone.

On the other hand this arrangement has the disadvantage that the patient is not well protected against stray radiation, electric shock, or injurious gases. The ends of the tube and the high tension leads are exposed and sparking to the patient may take place. On account of the high voltage used this is dangerous. The danger to life can be minimized by using rheostat instead of autotransformer control in the primary circuit or by the use of limited capacity transformers. The protection against stray radiation is subject to criticism. The lead glass bowls are open at the top; a tremendous amount of direct and reflected radiation can escape. The latter produces secondary radiation wherever it strikes, and this secondary radiation is scattered over the whole room. Such radiation can amount to approximately 1/30 of the intensity used to ray the patient. Hence it is advisable to cover the patient with leaded rubber. This may be done by laying the leaded rubber directly on the patient—a procedure not to be recommended—or by the use of stands, or frames with counter weights, etc., which, however, also introduces technical difficulties.

Fig. 47.

Lead Lined Tube Box (Cylinder), Designed and Built by the Acme International X-Ray Company, Chicago, Ill.

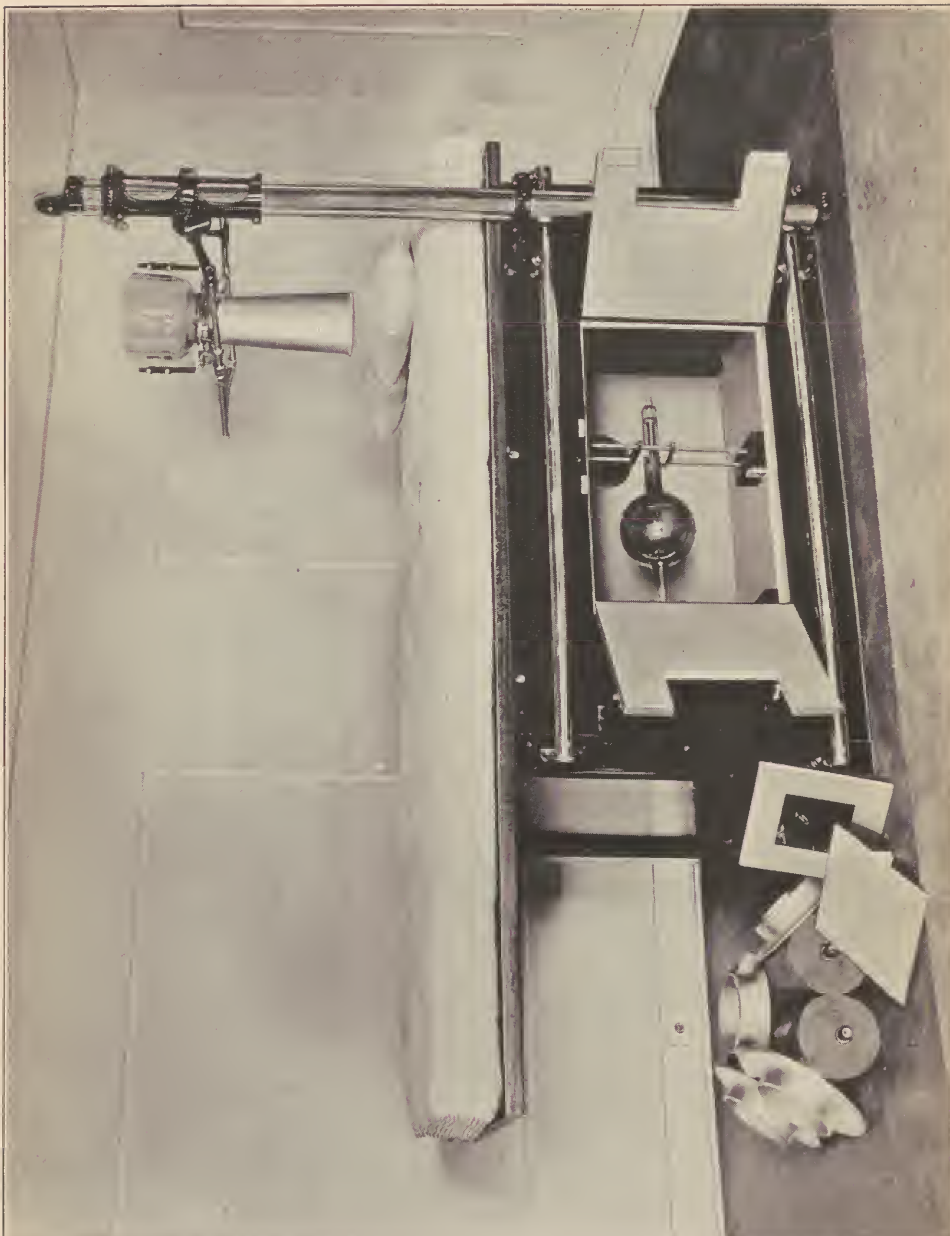


Fig. 48—Tube Holder with Treatment Cone Attached to Couch, Designed and Built by the Standard X-Ray Company, Chicago, Ill.

The exposed high tension lines and the stray radiation produce noxious gases, which must be removed by forced ventilation; there is also some danger to the tube on account of the proximity of the walls of the lead glass bowl. Large static charges, which cause sparking and endanger the tube, may accumulate. No conducting objects nor objects likely to accumulate charges should be brought near the tube.

(b) On the basis of these ideas tube boxes have been developed which enclose the entire tube (Fig. 47). A 5 millimeter layer of lead absorbs all undesired radiation. The rays can pass only through a single opening. On account of the weight of the holder special arrangements are made for adjusting it. In one design the tube box is always at the same level and the treatment table is adjustable; in another, the treatment table is fixed and the tube box is raised and lowered by some special device, such as counter weights or screws. In this way the desired focus skin distance can be attained. By a partial rotation of the tube box the central ray can be adjusted to any desired angle. By means of treatment cones the size of field can be fixed. If a ready means of adjustment is provided, the lead covered tube box can be regarded as the best type of apparatus: The protection of the patient is complete; noxious gases can be pumped out of the box; while the tube is protected against mechanical or electrical injury and also against overheating. Of course, the patient has to be considered as a source of radiation. The latter radiates an intensity about 1/100 of that emitted by the tube. For this reason the operator at least must be protected by a lead wall; also adjoining rooms must be shielded against the secondary radiation scattered by the patient.

(c) During the last few years another design has been developed, which has for its primary object the protection of the patient; the tube is mounted inside the treatment couch, and the patient placed on a mattress and rayed from below. This arrangement has the advantages that the patient is protected against the high voltage line, stray radiation, and noxious gases. At the same time the Roentgen installation is concealed. From the electrical standpoint there is a further advantage that the high tension line need not be carried through walls, since the space beneath the couch can open directly into the transformer room (Fig. 48).

However, an accurate raying of the patient becomes difficult for several reasons. First of all, a mattress which absorbs part of the radiation, is interposed. In most cases the mattress is supported by a wooden board which covers the opening through which the rays pass. This layer of wood also absorbs some of the radiation. The amount of this absorption must be known; in most cases it is considerable and steps should be taken to diminish it as far as practicable. The exact placing of the patient is difficult. The distance between target and skin varies with the pressure on the mattress. If the abdomen is rayed, full pressure is applied; if the breast or neck is rayed, the pressure is entirely lacking. The surface rayed may even be from 5 to 10 centimeters away from the supporting surface. This will introduce a considerable error in the dosage. If the patient covers the aperture completely, the boundaries of the field cannot be well determined. The only method possible is to determine the central ray indirectly; a plumb line can be passed over a pulley fastened to the ceiling at a point directly over the center of the aperture and the anti-

cathode can be set in the prolongation of the plumb line. In this way the point of emergence of the central ray can be determined and the point of entrance estimated; if the size of the aperture is known, the location of the boundaries of the field can also be estimated. Account must be taken of the fact that the skin is at a certain distance from the lead diaphragm and that the rays diverge in passing over this distance. For this reason the size of field will be uncertain. If the mattress is cut away over the aperture, new difficulties are encountered: a canvas must be stretched tightly over the opening, or, if this is inadequate, an air cushion must be inserted; or a cone with diaphragm and filter must be placed in the opening; however, this will cause a great deal of discomfort to the patient. In many cases where the breast is to be rayed, the patient cannot lie face downward. In view of these facts it is the opinion of the author that only a part of the needs apt to occur in practice are adequately provided for. A satisfactory dosage can be given only where there are few fields in quadrature; as in cases of carcinoma of the uterus; or where a single large field is to be treated and the limits of the beam need not be very exact. However, in cases where multiple ports of entry are employed and where there is danger of the beams overlapping, or in cases where a very small field is used and the beam must be accurately aimed at a given region, the above arrangement is far from adequate. The arrangement also is very apt to lead to routinary rather than individualized treatments.

(d) An improvement over the preceding arrangement is that in which the beam is sent horizontally through a window in the wall of the treatment room. If, in addition, the window is cut in a cylindrical surface,

a very flexible and easily examined arrangement results. (Figure 49.)

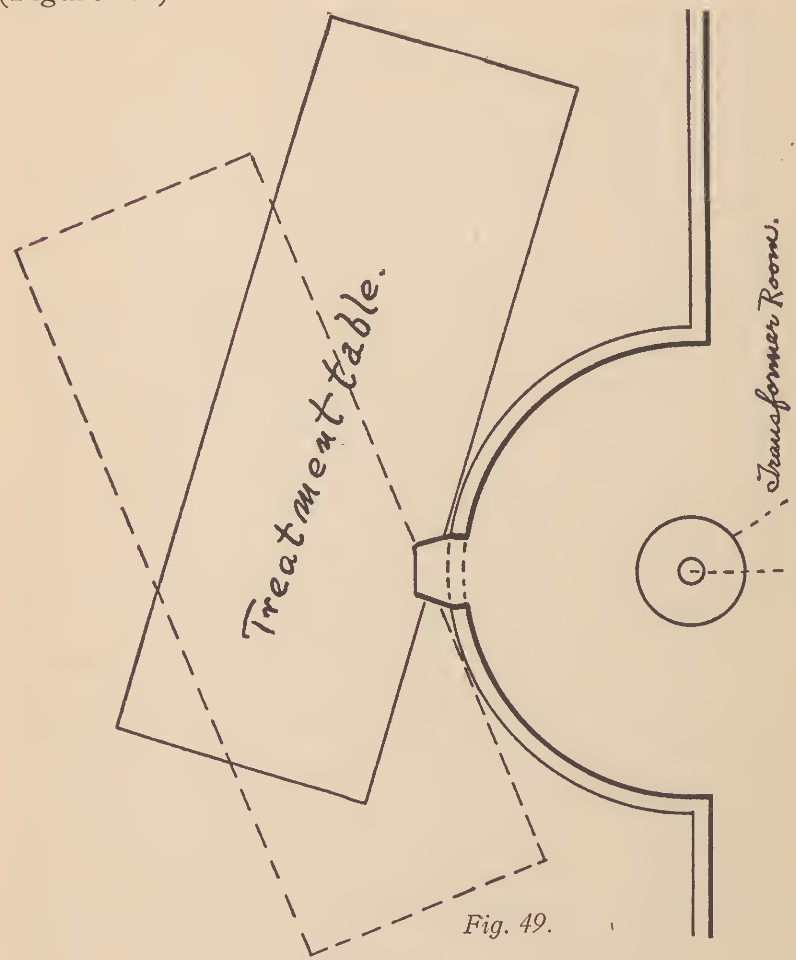


Fig. 49.

Roentgen Ray Installation, Tube Enclosed by Half Cylinder.

By means of an adjustable table the patient can be set at the proper height. The longitudinal axis of the table, and hence that of the patient, can be rotated to make any angle with the window. The patient can lie on the side,

Fig. 50.

Double Tube Roentgen Plant.
Combination of Couch and Half-Cylinder, Designed and Built for the Barnes Hospital, St. Louis, Mo., by L. C. Niedner of the Dick X-Ray Co., St. Louis, Mo.

face, or back. By sighting from above and from the side, the exact angle at which the central ray strikes the patient can be determined and the boundaries of the field observed. Hence, this arrangement is more flexible and convenient than the other. In fact, it combines the advantages of the tube box with that of the treatment couch.

Several other arrangements have been devised for special purposes. One of these is the Dessauer-Warnekross treatment bridge. The latter was designed to ray a surface perpendicularly and is capable of very exact adjustment. The tube is not enclosed and the patient must be protected with leaded rubber.

The arrangements described above cover in principle all the various possibilities; however, in particular cases an infinite number of variations and combinations are possible.

In the case of multiple tube operation a combination of two or more arrangements can be made (Fig. 50). It is also advisable to reserve an ordinary tube holder for use in those cases where the treatment couch cannot be employed. Fig. 48 illustrates such a unit.

A possibility not yet mentioned, of using the radiation of one tube to greater economy exists, namely, the simultaneous irradiation of two patients. This method is based on the fact, that up to 45° to one side of the central ray the intensity decreases only inappreciably, at most 5-10%.

Hence with one tube two patients can be rayed, the two central rays making an angle of 90° with each other. However, this angle can easily be chosen less than a right angle. Of course, each of the two patients must be shielded from the secondary radiation coming from the other.

An important point may be added. The lead diaphragm which limits the beam, and so determines the port of entry, should be as near as possible to the skin but not directly in contact with it. This is particularly important in cases where the beam is to be confined to a narrow field and also in cases where large fields are used and danger of an overlapping of the fields exists. If this requirement cannot be satisfied, the field should be bounded very accurately by means of leaded rubber fastened to the skin with adhesive paste. In the later case the lead diaphragm is the rough boundary and the leaded rubber the exact boundary of the field.

It is advisable to discuss the Roentgen sickness in this connection. According to Rieder and Holfelder Roentgen sickness may be due to three causes:

(1) Poisonous gases in the treatment room.

(2) Electrostatic charges influencing the cells of the body.

(3) Direct poisoning of some organ due to excessive dosage, particularly in the treatment of the stomach, liver, pancreas and suprarenals.

To avoid Roentgen sickness the following must be observed:

1. The production of ozone must be reduced to a minimum; this is best accomplished by installing the rectifier, spark gap, and tube in a separate room (couch, cylinder). The treatment room must be well ventilated. A large lead covered tube box equipped with blower to draw off the air is ideal.

2. Holfelder advises grounding the patient. If precautions are taken to avoid accidental electric shock, the grounding of the patient is not dangerous and may

be beneficial. In the case of the couch, the window and the tube box methods of treatment, it is not necessary.

3. The region rayed should not be too large; a well planned treatment avoids unnecessary exposure. The symptoms may also be mitigated by administering calcium chloride or by injecting it into the veins previous to the treatment. Voltz found a decrease in the chloride contents of the blood after intensive radiation. Pape accordingly increased the chlorine content of the blood by means of 200 cc of physiological Na Cl (sodium chloride) and Ca Cl_2 (calcium chloride) solution and avoided Roentgen sickness in many cases.

According to Hirsch an injurious effect of the rays on the endocrinal system is the chief cause of Roentgen sickness. His method is to carry out a preliminary treatment lasting from eight to fourteen days by injecting the extracts of endocrinal organs which are most likely to be damaged. He injects extracts of the following dutcless glands: the ovaries, the testicles, the thymus, the suprarenals and the hypophysis. He states that by this method the Roentgen sickness can be avoided. A combination of this method with that employing scopolamine or other hypnotics is not possible. Chloral hydrate and sodium bromide dissolved in tea and given per rectum may be used instead.

§2. Standardization of a Roengten Ray Installation.

After a Roentgen installation has been made, the roentgenologist is confronted by the following questions:

(a) What is the highest permissible operating voltage?

(b) What milliamperage can be sent through the tube?

(c) What is the correct focus skin distance and filter thickness for various purposes?

(d) What exposure time is required to produce various effects on the skin with the chosen operating conditions?

(e) What depth distribution is obtained with the chosen operating conditions?

All these questions are closely related and interdependent; they can be answered only by carrying out a series of experiments and measurements. This work is known as calibrating or standardizing the installation and will be described briefly.

In the first place the transformer and tube are aged.

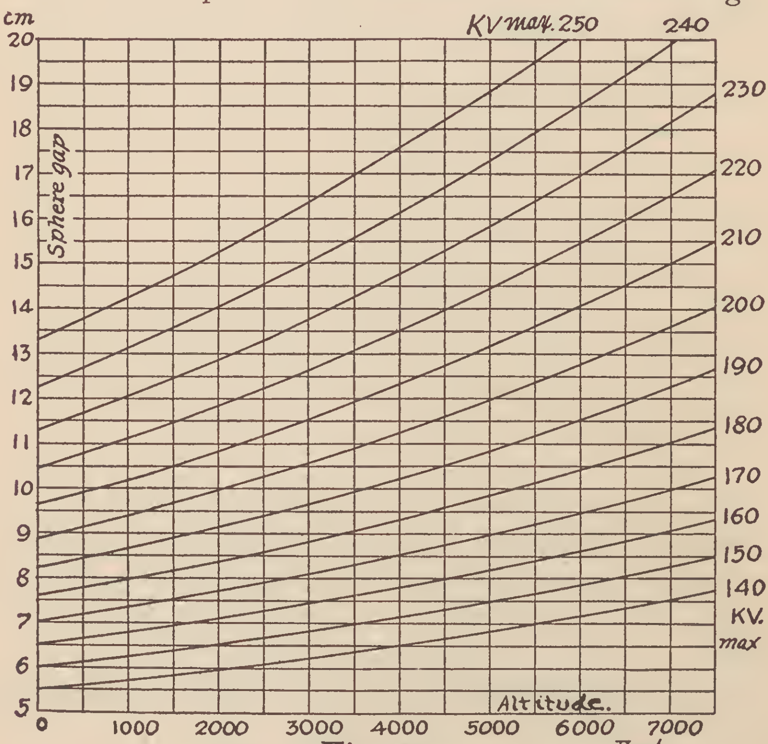


Fig. 51

Sphere Gap Reading at Various Altitudes.

This must be done with some care; there is danger of a breakdown in the transformer due to air bubbles in the windings. By running the transformer for some time at a low voltage these bubbles can be driven out; also with every new tube there is danger of breakdown caused by sudden releases of gas. By gradually increasing the voltage at a constant milliamperage the tube can be "seasoned."

During this time the measuring instruments may be tested for accuracy. The two milliammeters should read exactly the same. Some sphere gaps must be corrected for altitude, others are calibrated for various altitudes. The curves of Figure 51 show the relation between the kilovoltage and the "gap" when spheres 12.5 centimeters in diameter are used.

The following table gives the relation between the kilovoltage and the length of the spark gap in centimeters and in inches without any correction for altitude (760 millimeters, 25 C°).

Peak Voltage	Gap between points	
80 K V	11.1 cm	4.35 in
90 K V	13.3 cm	5.23 in
100 K V	15.5 cm	6.10 in
110 K V	17.7 cm	6.96 in
120 K V	19.8 cm	7.81 in
130 K V	22.0 cm	8.65 in
140 K V	24.1 cm	9.48 in
150 K V	26.1 cm	10.3 in
160 K V	28.1 cm	11.1 in
170 K V	30.1 cm	11.9 in
180 K V	32.0 cm	12.6 in
190 K V	33.9 cm	13.3 in
200 K V	35.7 cm	14.0 in

The length of the spark gap varies with the temperature but not more than a few per cent. The temperature corrections are given in the following table.

Temperature C°	Correction Factor
0°	1.09
10°	1.05
20°	1.02
30°	0.98
40°	0.94

The kilovoltage must be multiplied by the proper correction factor and the spark gap set at this new voltage.

The humidity of the air can be neglected.

It is very essential that a number of measurements of the kilovoltage with the same operating condition be consistent. If the readings vary considerably, the presence of surges is indicated. These usually start in at higher voltages and limit the kilovoltage that may be applied. By inserting a resistance of a half million ohms into the high tension circuit, the surges may be effectively damped. Diminishing the sparking of the rectifier is also beneficial. At the make there should not be a very large spark; but at the break a large spark must positively be avoided.

When the kilovoltage has been brought up to its proper value, the output of the tube under certain standard conditions is measured.

For this purpose the author uses the following conditions:

200 K V corrected sphere gap reading,
5 milliamperes,
1 millimeter copper plus 1 millimeter aluminum,
50 centimeters focus skin distance.

The measurements are made with an electroscope with which the output of a large number of Roentgen installations under the above conditions has been measured. This instrument, which is calibrated in "e" units, is controlled with a standard radium preparation and corrected for changes in pressure, etc.

With the above operating conditions an intensity of about 0.25 e per second should be produced.

If the intensity is much less than this, the operating conditions may be changed to 210 K V, 6 milliamperes; if greater, the milliamperage may be decreased to 4 milliamperes. When high kilovoltage and milliamperage is used, the constancy of the current through the tube should be carefully observed. Sudden increases in the current accompanied by fluorescence of the tube and crackling noises show that the safe voltage limit has been exceeded; a slow "softening" of the tube and a gradual change in the milliamperage shows that the current carrying capacity of the tube has been exceeded. If these phenomena appear even at low voltages and milliamperages, a stabilizer may be installed; however, a stabilizer should not be used if the primary current shows large fluctuations. Under these circumstances the potential fluctuations in the secondary circuit will be intensified by the stabilizer, due to the fact that the milliamperage is kept constant.

The filtration to be used depends on the results of both the intensity measurement and the hardness measurement. For deep therapy the absorption coefficient μ in water should be 0.175 or less; this value corresponds to an effective wave length of 0.15 A U. The depth ratio should not be less than 40 per cent with a large field and a focus skin distance of 50 centimeters. The filter thick-

ness should be sufficient to insure this hardness, but the intensity should not be diminished too much by the filter thickness. The intensity of the radiation under operating conditions should be large enough to produce a normal erythema in about 90 minutes. The exposure time can often be decreased to 70 or 80 minutes. Exposure times of 3 or 4 hours are absurd; either the apparatus is poor or the conditions have been incorrectly chosen.

The determination of the erythema time can be made with a reliable calibrated instrument. The best and most reliable instrument is, without a doubt, the electroscope, although its manipulation is not so simple. If it has been calibrated in "e" units, the erythema time can be determined from the fact that about 1800 "e" produce a mild erythema. Of course, account must be taken of the fact that with large fields up to 50 per cent of the primary energy is scattered back to the surface, i.e., to the skin. Hence the primary energy need be only about 1200 "e." If the installation delivers 10 "e" per minute, then 120 minutes are necessary to apply to required dosage. For softer rays the energy measured in "e" units should be somewhat lower.

Conclusive data is not as yet available on the variation of the relation between the biologic effect and the ionizing effect of rays of various degrees of hardness. However, the author's electroscope has been so calibrated by a large number of biologic observations that the erythema exposure time for any hardness can be calculated directly by multiplying by a numerical factor. The physical-biological factor, which of course, varies with the hardness, can be obtained by calibration for any instrument which measures a discharge time. The curve of Figure 52 gives this relation. For example, for a hardness corresponding to $\mu = .167$, the discharge time in

seconds must be multiplied by 7.0 in order to obtain the exposure time necessary to produce a definite erythema; by 6.0, in order to obtain the time necessary to produce a mild erythema; if the hardness is less, the factor

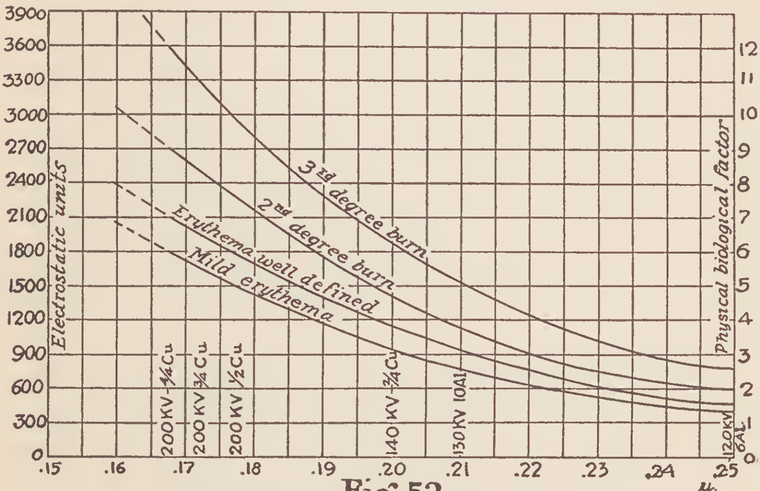


Fig. 52

Calibration Curves of Electroscope.

is smaller, the exact values for any case being given by the series of curves. Every single curve shows approximately the variation of the ionizing action and biologic action with the hardness. The "e" relation is not exact for soft rays since filters are interposed, scattered radiation obscures the exact relations, and the secondary radiation from the walls of the electroscope enters as a disturbing factor. On the other hand, the physical-biological-relation, as found empirically, is of great value for calibration purposes.

Iontoquantimeters can also be used for purposes of calibration. However, one must be sure that the constants of the instrument do not change and that the leak discharge is not too large. A correction of course must be made for leak discharge. Iontoquantimeters show

much smaller hardness errors than electroscopes; they are usually calibrated in terms of an erythema dose of 175 e (Friedrich) or of 1800 e (Bachem).

No calibration should be made by photographic methods since the errors involved are much too large.

The Fuerstenau intensimeters are calibrated in F/min. units. According to Fuerstenau 120 F are necessary with hard rays (200 K V, 1 mm copper) in order to produce an erythema. For soft rays (½ mm copper, ¼ mm copper) 110 F and 100 F respectively are necessary. For unfiltered radiation the hardness factor is very large, about 50 F produce an erythema. However, large variations occur between the readings of different instruments.

The hardness can be measured simplest in terms of μ or λ; but better and more comprehensive is a measurement of the depth dose with a water phantom and a small ionization chamber. Several exact measurements give a good idea of the intensity distribution within the medium.

By means of a calibration the Roentgenologist is enabled to begin raying at once without spending a few months in experimenting biologically for the correct dosage.

Besides the deep therapy radiation, several other radiations with less filtration should be examined.

The depth dose values corresponding to various kilovoltages and filters, as found by the author in experiments extending over a long period of time are given in Figure 53.

The constant factors in every case are 50 centimeters focus skin distance and large ports of entry: approximately 20 centimeters × 20 centimeters.

The curves show that increasing the voltage beyond a certain limit is of little value unless the filtration is simultaneously increased.

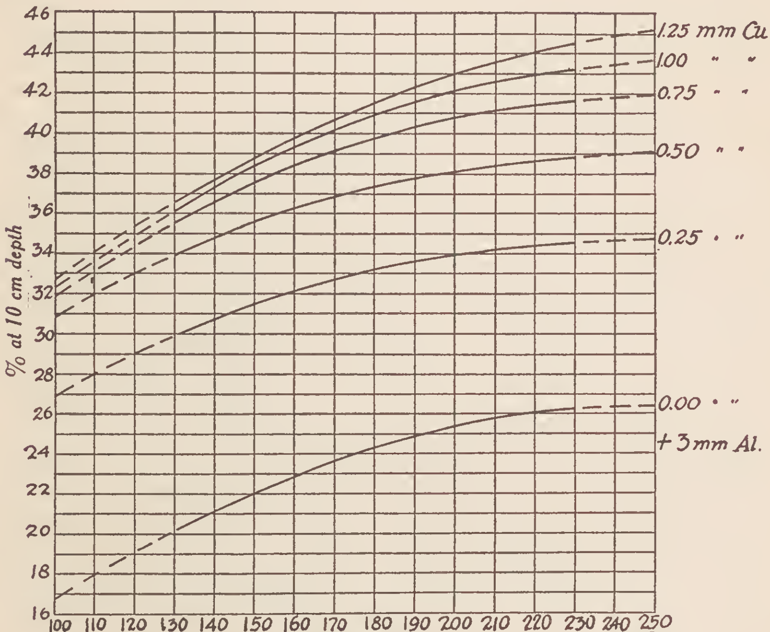


Fig. 53

Depth Doses for Different Kilovoltages and Filters, 50 CM F. S. D., Large Ports of Entry.

Beyond a certain limit it would even be advantageous to increase hte focus skin distance.

In the author's opinion two erroneous methods are in use at present:

(1) The distant field method (Wintz) employing a focus skin distance of a meter or more and insufficient filtration, namely, ½ millimeter of zinc;

(2) The thick filter method (Rapp) employing 2 or 3 millimeters of copper with a very small focus skin distance, namely, 23 centimeters.

In this category also belongs the method in which radium rays are filtered through 2 millimeters of lead, if no distance is used. Such strong filtration is useful only if a large surface, about 10 centimeters × 10 centimeters is rayed from a large distance, about 5 to 10 centimeters.

§3. Periodic Check of Installation.

The question may come up whether it is advisable to check the output of the installation by measurement from time to time. In answer it may be stated that this procedure is not as necessary as the first calibration, for the modern transformers and the Coolidge tube are very constant. As long as no factors are changed, an indirect dosage by milliampere minutes is easily possible. Of course, changes occur after the tube has been used for some time but these changes are taken care of by observing the erythema produced. If the treatment factors are changed for any reason, a great deal can be accomplished more quickly and conveniently by calculation. Of course, one will feel safer if he verifies the results of his calculations by measurements. In the opinion of the author, whether the Roentgenologist depends on his own measurements or uses curves and tables prepared by others, is entirely a question of his experimental skill and liking for physical measurements. If he wants a physical basis for the dosage, or, if he wants to draw any physical-biological conclusions from his results, he will not succeed without some kind of physical data.

§4. Determination of the Practical Dosage.

We now come to the discussion of the actual dosage, that is, a determination of the correct quantity of radiation for the treatment. First, let us consider the possible methods:

(1) The ideal method would be to determine the absorbed energy which is biologically effective. This requirement is approximated by the method of Friedrich employing iontoquantimeters with small chambers.

(2) According to Dessauer a knowledge of the surface intensity is sufficient to predict the biological action from empirical data on the effect of hardness. This method has been developed by the author into a process of calibration.

(a) In the case of a fairly homogeneous radiation and approximately the same absorbing material, the error due to hardness disappears; this makes a simple dosage possible in deep therapy. This is the basis of Dessauer's method.

(b) In the case of a combination of Roentgen and radium radiations or of Roentgen rays of various degrees of hardness, the homogeneity vanishes. For this case the author has modified the method customary in practice of adding rays of different degrees of hardness in terms of their biological values.

The method of Friedrich has been discussed in detail in connection with iontoquantimeter measurements. The method of Dessauer will be illustrated in the following by a series of examples of deep therapy treatments. A few cases of combined Roentgen and radium treatments will also be given to demonstrate the use of radium charts with biologic scales.

The energy which the surface receives is made up of a series of components:

(1) The primary energy rayed directly to the field,

(2) The energy scattered back by the interior, and

(3) The energy coming from other ports of entry (if multiple fields are used), and emerging at the surface in question.

To determine the correct total surface energy two methods can be used: the first method resorts chiefly to measurements, the second to computation.

(a) In the first method the sum of the components (1) and (2) is measured with an instrument that indicates the total scattered radiation. The small ionization chamber is best suited for this purpose; it is pressed down to lie half way within the surface; the measurement is carried out with all conditions exactly the same as they will be in the treatment; in particular with the correct size of field. This measurement gives the total energy supplied by the first port of entry.

The intensity which reaches the surface in question from other ports of entry can be measured if the patient is put in the corresponding position; of course, the intensity is found only after the field has received a strong exposure. However, it is very important that the distribution over the surface and at different points in the interior be known before the treatment is begun. Hence the second method is better suited to the purpose.

(b) This method presupposes a calibration of the installation and constancy of the apparatus. The exposure time required to produce an erythema with a definite field, say 20 centimeters $\times$ 20 centimeters therefore is known. From preceding considerations one can easily deduce how much longer the exposure time is for a smaller field; however, energy is supplied to any one field by all the others. From the curves already given the amount of this energy can be estimated and the time must be correspondingly decreased.

An example may serve to make this clearer:

The erythema exposure time for a field 20 centimeters $\times$ 20 centimeters is 100 minutes.

A field of 15 centimeters × 15 centimeters is required.

Figure 37b gives the erythema time factor as 1.05.

Hence the erythema exposure time must be increased by 5 per cent; that is, 105 minutes must be used. Two such fields should be given one posteriorly, one anteriorly. The thickness of the patient is assumed to be 15 centimeters.

The graph (Figure 37b) shows that 20% — ⅕ of 20% or 16% penetrates the body. With 2 × 105 minutes, therefore, an energy of 100 + 16 = 116% would be applied. Hence the time must be decreased in the ratio 116:100; that is

$$116 : 100 = 105 : x$$

from which $x = 90$ min.

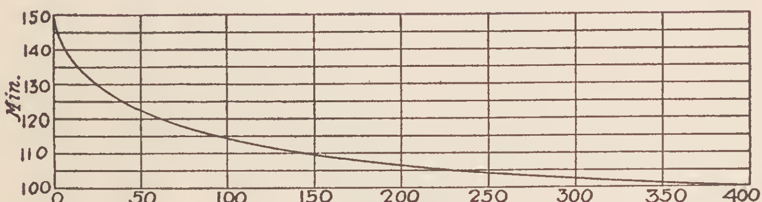


Fig. 54

Variation of Exposure Time with Size of Field.
200 KV.
¾ MM Cu.
50 CM F. S. D.

A curve can be constructed giving the increase in time necessary for various smaller fields. (Figure 54.) The horizontal axis indicates size of field; the vertical axis gives the time required for any field provided the erythema exposure time for a field 20 centimeters × 20 centimeters (= 400 square centimeters) is set equal to 100. In other words it gives the new exposure time

directly in per cent of the exposure time required for a field 20 centimeters × 20 centimeters (= 400 square centimeters).

The correction which must be applied due to the addition of a second field directly opposite the first, can be exhibited graphically as a function of the thickness of the medium rayed (thickness of abdomen, leg, etc). (Figure 55.)

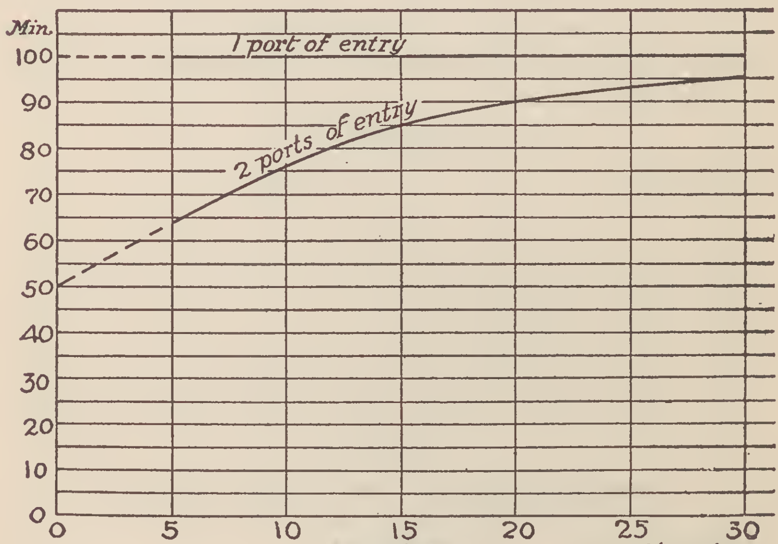


Fig. 55

The Effect of Diameter of Patient on Exposure Time.
200 KV.
¾ MM Cu.
50 CM F. S. D.
Large Ports of Entry.

While with a single field 100 minutes are required independent of the thickness of the layer rayed, with two fields the time must be decreased as the thickness

of the layer is increased. To every thickness there corresponds an exposure time as is shown by the curve.

The correct surface dosage is important for two reasons: First of all, the skin reaction depends on it; with too strong an exposure there is danger of serious injury. Secondly, the amount of energy applied to the skin is taken as a measure of the amount of energy applied at various points within the interior. For this reason the amount of energy applied to the skin should be accurately known even though no skin reaction is produced. Without a knowledge of the energy at the surface, the energy at a depth cannot be estimated. Hence we must discuss the depth distribution simultaneously with the surface distribution.

The determination of the intensity in the interior is very simple when the central ray only need be considered; this is actually the case when only two fields lying directly opposite are applied. Then the curves which give the distribution along the central ray may be used.

Let us take as an illustration the case of

200 K V;

1 millimeter copper + 1 millimeter aluminum;

50 centimeters focus skin distance;

2 fields 20 centimeters × 20 centimeters;

Erythema time, 120 minutes;

17 centimeters anterior-posterior diameter;

The uterus is to be treated.

Let the uterus be situated 8 centimeters from the anterior wall, the bladder 6 centimeters, the rectum 11 centimeters. The estimation may then be made with the help of the chart (Figure 35), according to the following table:

Region	Centimeters		%	%	Total	Reduced
Surface anterior	0	17	100	15	115	100
Bladder	6	11	63	35	98	85
Uterus (inside)	8	9	50	44	94	82
Uterus (outside)	9	8	48	45	93	82
Rectum	11	6	35	63	98	85
Surface posterior	17	0	15	100	115	100
Time			120	120	2×120	2×104

With the full exposure time the surface receives 115 per cent, the uterus and rectum less than 100 per cent. It appears that the surface energy is too high and the time of exposure must be decreased so that the surface receives 100 per cent. The exposure time must be changed to 2×104 minutes; but a point in the interior then receives only 81 to 85 per cent.

The situation is more complicated when a larger number of fields are used; a consideration of the distribution along the central ray then is no longer sufficient; the same applies when some organ, the suprarenal glands, for example, must be protected. In both these instances the charts which show the distribution throughout the interior must be used (Figure 37).

Such charts were first published by Dessauer and Vierheller; also the method of using these charts for the calculation of the effect at various depths was originated by Dessauer.

As an illustration let us take another uterus case; the dimensions involved are shown in the accompanying figure (Figure 56).

The figure should be drawn in natural size on transparent paper. The dimensions can be obtained in various ways; with a pelvimeter the diameter of the patient and

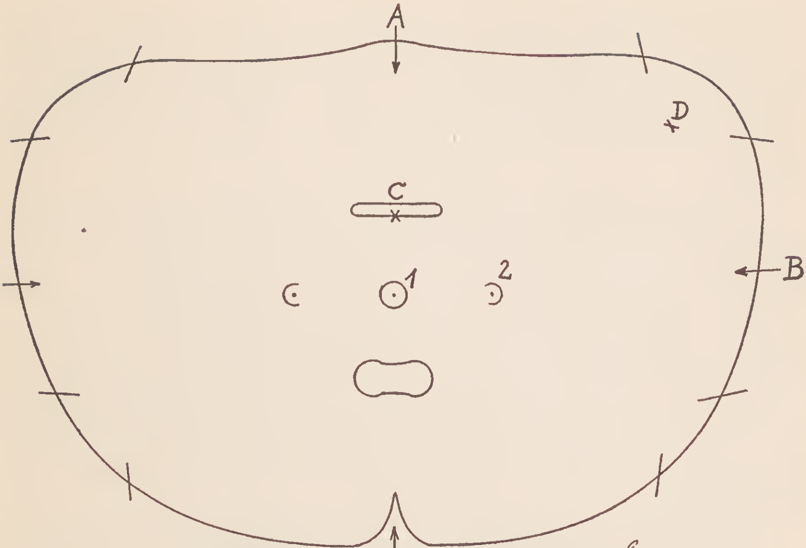


Fig. 56. 1/3 Actual Size

Abdominal Cross-Section of Patient.

the distance of the uterus from the surface can be determined very exactly; with a tape measure and two plane sticks (metersticks or rulers) the anterior-posterior diameter and transverse diameter can be ascertained. This is best done with the patient lying down. The outline of the cross section can be determined very simply and exactly by the use of a strip of lead about 1 meter long, 2 to 3 millimeters in thickness, and 1 to 2 centimeters in width, which is hinged in the middle. The outline of the cross section can best be determined by this method, but the anterior-posterior diameter should be checked with a meter tape. All points of importance should be marked with numbers or letters.

A table is made as shown on the following page; then the isodosage charts corresponding to the treatment factors to be used are laid under the transparent paper and the distribution read off and entered in the table.

For our case let us take 200 K V, ¾ millimeter copper, 50 centimeters focus skin distance, various fields depending on the patient, patient 20 centimeters thickness. Let the erythema time for a large field be 100 minutes.

A field of 20 centimeters × 20 centimeters can be applied to the anterior and the posterior wall. The boundaries of the field are marked on the figure. On account of the crossing of the beams only smaller fields, say 10 centimeters × 10 centimeters or 10 centimeters × 20 centimeters can be applied. Overlapping of fields perpendicular to each other is only dangerous at the skin; a few centimeters below the surface there is, in general, little danger.

The table is now filled out with the proper values as given by the underlying charts. It must be observed that the values given are valid only for points which lie in the surface of entrance or in the interior of a large volume. For points lying in surfaces of emergence, 20 per cent of the indicated values must be subtracted.

	Skin		Bladder (rectum)	Over Lapping	Cancer Uterus	Cancer Broad lgt.	Time	
Ports of entry	A	B	C	D	1	2	Total	Reduced
	%	%	%	%	%	%	Min	Min
Anterior	100	9	56	49	40	38	100	84
Posterior	11	8	28	11	40	38	100	84
Right	5	100	16	59	17	30	115	96
Left	4	1	16	1	17	9	115	96
Total Amount	120	118	116	120	114	115		
Reduced Amt.	100	98	96	100	95	95		

A study of the results shows that a very uniformly distributed energy is applied by the four fields. Points in the interior receive practically as much as points near the surface. Such a distribution is said to be homogeneous. The term "homogeneous" in this instance refers to the quantity of radiation, not to the quality as was the case in the discussion of the spectral composition of radiation.

To differentiate between the usages one might speak of spectral homogeneity and space homogeneity. The first is attained by the use of the proper filter, the second, by the proper application of the radiation.

In cases where a full erythema (100%) is desired, an application of 120 per cent would greatly over expose the skin. The time would have to be decreased in the ratio of 120:100; instead of 100 minutes, 84 minutes would be required for the anterior and the posterior field; instead of 115 minutes, 96 minutes would be required for the lateral fields.

The foregoing example is given to show how the determination of the energy distribution is carried out. In all the treatment cases given in the next chapter, the calculations have been made by this method. A larger number of points have been used, however, so that the isodosage lines could be drawn.

In Chapter III isodosage charts are given drawn in terms of a scale such that the application of an energy of 100 produces a certain erythema. These tables enable an easy estimation of the applied energy, of the necessary exposure time, moreover, enable a combination of Roentgen and radium energies. If, for example, we are dealing with a case of carcinoma of the cervix of the uterus and a 50 milligram tube with 1.5 mm brass

filtration is to be used, the calculations can be made with the help of Figure 42.

This chart shows the energy distribution for an application of 1000 milligram hours. It is best used by making a cross sectional drawing of the abdomen on a sheet of transparent paper. Usually a rough diagram which indicates the approximate location of the organs will be sufficient. If this drawing is placed on the chart,

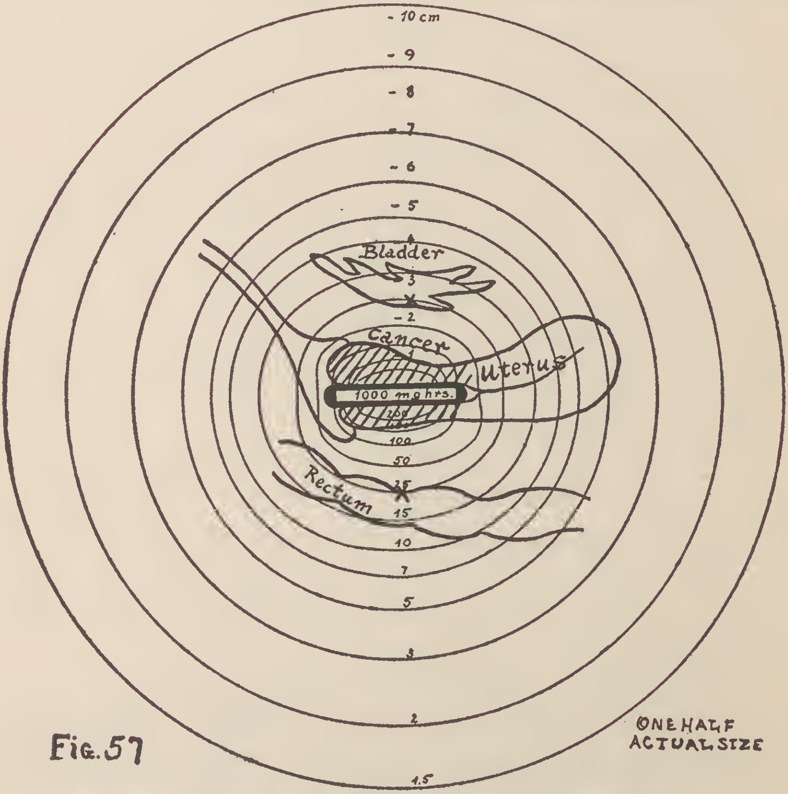


Fig. 57

Treatment of the Inner Pelvis with a Radium Capsule.

it is easy to observe the depth at which the preparation must be placed so that the isodosage lines envelop the cancer growth as completely as possible. (Figure 57.)

Next it is determined whether every point of the tis-

sue to be rayed receives a sufficient energy. In our case a portion of the malignancy extends beyond the 100 line. It would therefore not receive sufficient radiation. If double the number of milligram hours are given the isodosage line, 100 will be displaced to the position of the present isodosage line 50; then every part of the cancer growth will receive an energy greater than would correspond to an erythema. If an energy of 150 per cent is to be applied, 3000 milligram hours must be employed. The energy at the bladder and at the rectum must be noted; these regions should not receive a great deal more than 100 per cent. Since they receive 25 per cent with 1000 milligram hours, 4000 milligram hours appears to be the upper limit. Only in exceptional cases should more than this be applied.

If Roentgen energy has already been supplied to the tissues, it must be taken into consideration. Let us again refer to the case of a patient rayed with two fields (page 208) and let us consider, first, the addition of 500 and, second, the addition of 1000 milligram hours of radium element. This addition is permissible since 100 on the Roentgen ray chart and 100 on the radium isodosage chart biologically mean the same thing, if proper doses are combined.

	Roentgen energy	500 mg hrs	Total	1000 mg hrs	Total
Surface anterior	100%	1%	101%	2%	102%
Bladder, 2 cm	85%	20%	105%	40%	125%
Uterus inside	82%	∞	∞	∞	∞
Uterus outside	82%	50%	132%	100%	182%
Rectum, 3 cm	85%	10%	95%	20%	105%
Surface posterior	100%	1%	101%	2%	102%

The combination of the Roentgen ray treatment with 500 milligram hours of radium treatment would represent sufficient radiation for a case of a carcinoma of the basal type; the bladder and the rectum would not be harmed. If an application of 175 per cent were required for a carcinoma of the cylindrical cell type, 1000 milligram hours would have to be applied. In this treatment the bladder would be irritated. Further development of this example shows that the broad ligaments, which are situated about 4 centimeters from the preparation at right angles to the plane of the drawing, would receive only 10 per cent when 1000 milligram hours are used. An intense raying of the broad ligaments therefore cannot be carried out with radium or even with radium combined with a weak Roentgen radiation but is possible only with a homogeneous Roentgen radiation combined with a light radium treatment.

An example of the graphical representation of radium dosage is the following:

A sarcoma of the cheek is to be treated with radium needles. The needles are to be placed at such distances apart and are to remain for such a period of time that no point of the intervening tissue receives less than an erythema dose.

Geometrically a triangular distribution seems to be most favorable. (Figure 58.)

The mid points of the triangle will receive the least energy. Hence they must receive at least one-third an erythema dose from each vertex. Figure 43 shows the energy distribution in biologic units when 100 milligram hours are applied.

A third of an erythema is produced at a distance of 10 millimeters. Hence the vertices of the triangles

should not be more than 10 millimeters from the mid point. This is the case when the side of the triangle is 1.7 centimeters in length. Hence the needles must be placed 1.7 centimeters apart.

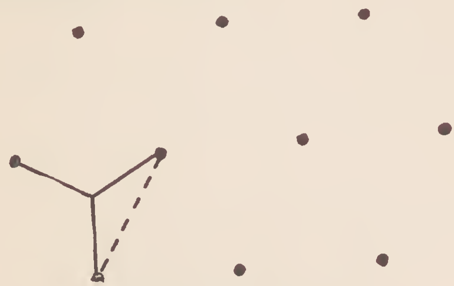


Fig. 58—Actual Size.
Calculation of Dosage for a Number of Radium Needles.

If an epithelioma is to be treated, an energy of 175 per cent may be required; each preparation must supply about 60 per cent and this energy exists within a radius of 8 millimeters; hence the side of the triangle in this case is about 1.3 centimeter. Of course, by a decrease in exposure time, an equal energy more uniformly distributed can be applied.

All these calculations are only to indicate the method of exact dosage. In the following chapter the treatment methods employed in practice are analyzed by this method and critically examined from the standpoint of physics. Attempts have also been made (in the next chapter) to develop new methods which satisfy the needs of the radiologists.

§5. Determination of the Total Energy Applied.

All the preceding determinations of quantity of radiation were based on energy density, energy per unit volume, or intensity per unit surface. The total energy sup-

plied to the body was not considered. However, it is this total energy which determines the general reaction of the patient to the treatment since the damages to the blood and tissues depend directly on this quantity.

On this basis Wintz has introduced the so-called "a" unit which defines the total energy applied to the tissues; "a" is the amount of energy which is applied to the tissues under the following conditions:

180 K V;

0.5 millimeter zinc filtration;

23 centimeters focus skin distance;

6 centimeters × 8 centimeters field;

Unit skin dose as the biologic measure of the surface energy;

15 centimeters thickness of the patient.

With an application of 3 a or less, only slight blood changes are said to occur; with 5 to 7 a they are of a serious nature and continue for 5 or 6 weeks. Unfortunately, the Wintz "a" unit is practically limited in its sphere of application to the Wintz technique; to apply it to the totally different treatment technique which is used everywhere else is impossible; hence this magnitude cannot be spoken of as a "unit."

For the treatment technique used in this country a total energy quantum could be defined by the following factors:

200 K V;

1 millimeter copper;

50 centimeters focus skin distance;

20 centimeters × 20 centimeters size of field;

1800 "e" at the surface;

20 centimeters thickness of the patient.

The factor which varies the most is very likely the

size of field, but the effect of the latter on the total energy can easily be determined; the table given below shows the relation between the two. However, the energy supplied to the patient can be given without difficulty in electrostatic units; it is then based on a physical measure already in use and can really be spoken of as a unit since it enables comparisons even with very different factors and methods of treatment.

In the production of a mild erythema an energy of 1800 e is applied to one cubic centimeter of the skin near the central ray. By the use of distribution charts the ionization produced in each cubic centimeter of the body can be determined and expressed in electrostatic units.

This computation has been carried out with the four charts for a medium sized patient (20 centimeters diameter) with the following results:

for	(20 centimeters)^2	10×10^6 e
	(15 centimeters)^2	5×10^6 e
	(10 centimeters)^2	3.3×10^6 e
	(5 centimeters)^2	1×10^6 e

These figures permit a comparison of the absorbed energies as a function of the size of field. These energies are not in the exact ratio of the areas of the ports of entry. They also permit an estimation of the applied energy for various treatment methods. For example, the total energy applied by 5 small fields is 5×10^6 e; by 2 large fields 2×10^7 e.

An application of 4 fields produces

$$
\begin{aligned}
& \; 2 \times 10^7 \\
& + 2 \times 5 \times 10^6 \\
& = \; 3 \times 10^7 \text{ e.}
\end{aligned}
$$

The concept of total energy is still in a stage of development in physics and is not yet very exact. From the

biologic side also there is a great deal to be explained. It is certain, that beside the total energy, the distribution of the energy to the various organs, spleen, pancreas, stomach, etc., is also important. Different effects are also to be expected if a large region is rayed homogeneously or very unhomogeneously even with the same total energy. In the last case necrosis could produce very different effects than the uniform total reaction would produce in the first case. However, all these matters are still so obscure that further discussion is hardly worth while.

For this reason the total energy applied with radium preparations has been omitted; in these cases the distribution is very unhomogeneous and as a result the biologic effects vary tremendously with the distance from the source of the radiation and with the region of application.

§6. Aids to Practical Dosage.

A few aids to practical dosage may be mentioned.

(1) Sensitizing of tissue.

Since tissue congested with blood is more sensitive to radiation, the suggestion has been made to treat the region to be rayed beforehand with diathermy. The congestion produced in this way is supposed to make the tissues more sensitive. A few observations appear to verify this conclusion.

The introduction of secondary radiators in the tissues is said to increase the effective dosage at the point in question. Experiments of Kroenig and Friedrich with a series of secondary rays did not verify this statement.

Wintz has shown on the contrary, that with a deposit of copper on the skin a dosage of 90 per cent of a unit skin dose produced a normal erythema while a dosage of

120 to 130 per cent produced a second degree burn. On this basis Wintz has introduced the copperization of carcinoma tissue. A sponge electrode saturated with a 5 per cent solution of copper is brought as near as possible to the cancer tissue; a cathode of inactive material is placed on the surface of the body. A current of 20 M. A. supplied by a storage battery is sent through the circuit for four hours. The radiation is then carried out. Wintz reports favorable results. However, it is doubtful whether the effect can be explained on the basis of secondary radiation; it is possible that we are dealing with the addition of biologic processes, as was found to be the case by Halberstaedter in the action of iodine on the skin.

The cells of the body are most radio-sensitive at the instant of their division. Hence one method which promises to be successful is to distribute the raying over such a period that all the cells go through a division during this time. Of course, the correct exposure time would be different for various tumors depending on their rapidity of growth. A series of 2, 3 or 4 single treatments distributed over a week would appear to be best. The first treatment might cause or accelerate the cell division and this would make them more sensitive to the following treatments. Two limits appear to be fixed by these considerations:

(a) A lower limit. The time could be too short in order to catch all the cells in their division period. The existence of such a limit appears to have been verified by a series of experiments. Wood found that with short exposure times a larger number of milligram hours of radium were required to produce the same results as were obtained with weaker preparations and longer exposure times. Similar results were obtained by New-

comet and by R. H. Stevens in comparing short and long radium treatments. With Roentgen radiation Wintz found that a distribution of the energy over 17 hours produced a better effect on breast cancers than a concentration of the energy into 2 hours.

(b) An upper limit of the exposure time is defined as the period within which new masses of cells may be formed, which cannot be as succesfully treated by the next radiation as the original cells. In this case we are dealing with interrupted dosage. Observations were made by Seitz and Wintz on cases of interrupted dosage. The large doses given by Kehrer are also explained by the fact that the dosage is divided, i.e., given at intervals over a period of time. Juengling and Werner report that with interrupted Roentgen dosage 20 to 30 per cent more energy must be applied in order to attain the same results.

(2) Desensitizing of tissue.

Tissues which contain little blood are less sentive to radiation than normal tissues. By compression the amount of blood in a region can be reduced. Observations show weaker reactions of compressed skin and connective tissue. Also the Roentgen sickness can be reduced since the volume of blood rayed is reduced.

(3) The value of superimposed layers.

Layers of wax, paraffin, bolus alba, water and other similar substances have frequently been recommended and used. Their action is said to be due to two causes:

(a) An improvement of the depth dose. However, according to the latest investigations of Glocker and his coworkers, as well as from the isodosage charts of Glasser and of the author, such an effect does not exist; on the contrary, the distribution in the interior becomes less favorable.

(b) An improvement of the homogeneity in cross fire treatment of superficial growths or small parts of the body (neck, arm, knee, etc.). Such parts cannot be easily treated from different angles without danger of crossing the beams and producing burns. By the use of cover layers large fields can be applied from 2, 3 or 4 sides without danger of burns. In the author's opinion the suggestion made by many radiologists to use water bags, which are arranged as illustrated in Figure 59, is a good one.

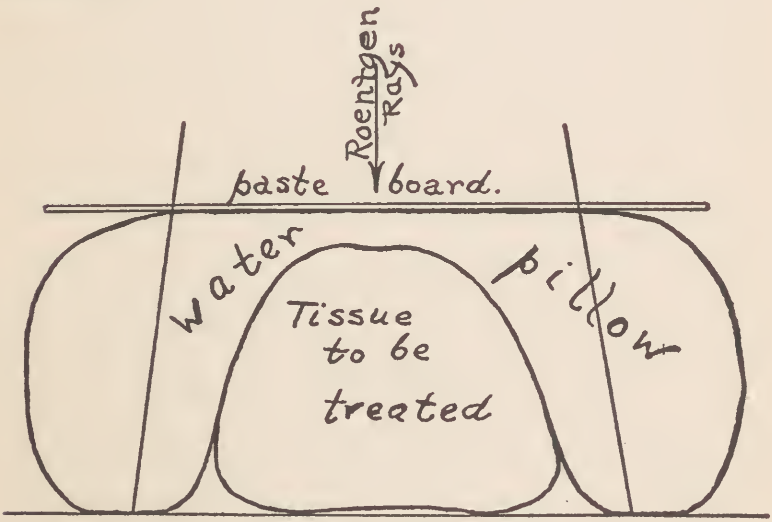


Fig. 59.

Superposed Layers.

The bag is so filled that by the application of slight pressure it may be fitted very exactly to the outline of the support. The surface is formed by a cardboard. The thickness of the water layer is determined by inserting a stick graduated in centimeters through a hole in the cardboard.

CHAPTER V

Examples of Treatments

§ 1. Biologic facts underlying dosage.

In the preceding chapters the physical and the technical aids to correct dosage have been discussed. We may now take up the biologic phenomena which form the basis of dosage. A natural classification is given by the observations of all investigators that very small doses are stimulating, that larger doses arrest anabolism, and that very strong doses are fatal to all tissues.

Hence we may first discuss those treatments in which radium or Roentgen rays have a stimulating action on a series of biological processes.

Under this head belongs the stimulation of the blood forming organs. An injection of less than 1 microcurie of radium element or the inhalation of approximately 100 emans produces a leucocytosis in a few hours. According to Gudzent the increase in white blood cells depends only slightly on the strength of the dose. The latter was varied from 10 to 700 emans per liter, the treatment consuming two hours daily. A leucocytosis appeared even with very small doses, with larger doses it was only slightly greater. Also short irradiations, approximately 100 e or 1/20 of an erythema dose, produce this increase, which, however, with a single application is of short duration; but by continued treatments an average increase persisting for a long time can be attained. Frequently an increase of the lymphocytes and an increase in the phagocytic power of the lymphocytes can be verified. An

increase of the red blood corpuscles is also observed when small, though somewhat larger doses than in the preceding cases, are given. The effect is less pronounced than the other and shows a lesser sensitivity of the red blood corpuscles as compared with the white ones. A greater increase is noted in pathologically anemic patients; in these cases doses of about 10 microcuries can bring the number of red corpuscles to normal in a few days. The increase of the red corpuscles persists longer than does that of the white. The coagulation time of the blood also is considerably shortened by the application of the above mentioned doses; the effect, however, is only temporary. With large doses the coagulation time is increased.

All these effects seem to be produced chiefly by the action of the rays on the blood forming organs: the spleen, the bone marrow, and the lymphatic glands. These tissues are very sensitive to radium and Roentgen radiation. When injections are made the greatest concentration of the radioactive elements is found after a few days in the spine and the spleen.

The above mentioned effects of the rays on the blood and blood forming organs have led to radiation treatment of the following cases:

Pernicious anemia: according to Gudzent intravenous or intramuscular injections, two at the most, of 0.010 milligrams of radium element at an interval of 14 days may be given.

Chronic suppuration and inflammations; open sores, cuts, wounds and burns: small, stimulating doses of soft radiation are given at frequent intervals.

Preoperative irradiation: By raying a short time before an operation the loss of blood can be decreased.

For these purposes a stimulating irradiation of the spleen is recommended.

A further well-known effect of small Roentgen ray and radium doses is the stimulation of metabolism; the effect on purin metabolism is especially pronounced. By an increased diuresis the uric acid content is diminished. Gas metabolism is also increased; the assimilation of oxygen and excretion of carbon dioxide is accelerated.

These facts have led to radiation treatment of subacute and chronic articular rheumatism or gout, myalgia, and muscular rheumatism.

Inhalations, injections, and oral administration are recommended. Gudzent injected soluble radium salts in doses of 0.02 milligram of radium in five intervals of 8 days. The same author administered emanation by inhalation; the concentration used varied from 11 to 130 emans per liter, a sitting lasting for 2 hours, and the total number of sittings varying from 24 to 40. The oral administration consisted of 5 portions of 3,000 to 400,000 emans daily for an average period of six weeks. Combinations of inhalations and injections were also employed.

Another effect of the rays is that on the blood pressure. The blood pressure, especially if pathologically increased, is lowered by stimulating doses, probably due to a stimulation of the vaso-motor nerves. On this fact is based the treatment of myocarditis, neuroses of the heart, arteriosclerosis, etc.

In the case of the diseases which have just been described the curative or palliative action of the radium or X rays is one of stimulation of cells and organs to increased proliferation and function. These actions have also been observed and employed in other cases. Martius

observed a stimulation of the ovaries when small doses were employed, although he warns against the irradiation treatment of amenorrhoea, since idiosyncrasies cause large variations in dosage, and since an over-dose may easily lead to a cessation of the overian function.

For the treatment of stomach ulcers stimulating doses have also been tried. Schulze Berge recommended 40% of the unit skin dose, and reported good results. Menzer employed much smaller doses, which, however, were repeated every week. These good results were confirmed by many radiologists.

Also in the radiation treatment of tuberculosis we are dealing, according to most authors, with a stimulating action of the rays. On account of the low sensitivity of the tubercle bacilli to irradiation, they cannot be destroyed without harm to the surrounding tissues. Some 100 hours of exposure to beta rays coming from a full strength plaque are necessary to kill the tubercle bacilli; smaller doses, of course, do have an impairing effect on the bacilli. Various authors give various explanations of the action of the rays:

Stephan believes in the stimulation of the proliferating tissue and gives doses between 1/40 and 1/20 of a unit skin dose in cases of tuberculosis of the lungs.

Hilpert also believes in stimulating doses and begins with 6% of a unit skin dose but gradually increases this to 20%. The treatments are given at intervals of 4-8 days and are continued for 6 weeks. The dose must be increased during this period because the cells become accustomed to the stimulation dose; the larger doses are not dangerous because the cells become more resistant with repeated applications.

Holfelder also is of the opinion that the action of the Roentgen rays consists in a stimulation of the demarcation zone. The doses recommended by him are greater than those mentioned above. In cases of tuberculosis of the joints he recommends doses of 20% to 60% for the entire diseased region and proposes longer pauses: 8-12 weeks after the first irradiation, 12-16 weeks after the second, 6-8 months after the third, and 8-12 months after the fourth. Smaller doses are given in the last few treatments. He considers it of great importance that the encapsulation of the tuberculous area proceed slowly, since then the danger of a rupture of the protecting walls is lessened. Juengling and Lehmann ray the diseased region homogeneously with similar doses, 20-50% and 25-30%, respectively.

Contrary to these authors, Altschul believes the action of the rays on the skin is all important and a homogeneous irradiation with hard rays beside the point. He proposes the use of 1 mm of aluminum and in this way puts the treatment of tuberculosis into the field of superficial therapy. His view is that the absorption of the rays in the skin stimulates, analagous to pigmentation in heliotherapy, a sort of endocrin function of the skin, which in time acts indirectly on the tuberculous tissue.

Gudzent believes that besides stimulating the connecitve tissue the rays also take part in the destruction of the tuberculous proliferating tissue.

In spite of the various assumptions as to the action of the rays, all authors agree that a stimulating action must be attained and therefore employ small doses. Nevertheless dosages of 20-60%, and more so the cumulative doses, are already far in excess of the doses ordinarily assumed as stimulating.

Differences of opinion are found when it comes to the question of what hardness is to be used, in particular, whether hard or soft rays are the more advantageous. One thing is certain, however, namely, that very hard rays are neither requisite nor desirable in the treatment of tuberculosis. Also in the treatment of tuberculosis cutis or lupus vulgaris the Roentgen therapy is based more on a stimulating effect on the connective tissue than on a destructive action. Hence relatively small doses are given in series treatments. On account of the superficial nature of the disease rather soft rays can be used.

Holzknecht uses an 8-10 inch gap, 18-25 cm. focus skin distance, 1-2 mm. aluminum filter and 4-6 H.; this is less than an erythema dose (8 H); and repeats this dose several times at intervals of 4-6 weeks.

Altmann filters with 4 mm. aluminum (2.5-2.8 cm. half value layer) and gives 6-7 H., hence also less than an erythema dose (10 H.), and repeats at the customary intervals.

McKee also uses doses which do not exceed the epilation dose at intervals of four weeks and warns against the production of a strong skin reaction.

The radium treatment of lupus vulgaris is similar to Roentgen treatment when small doses and small focus distances are used. However, there is in use a beta ray method by which a superficial necrosis is produced just once. It seems that the action in this case is produced both by a destruction of the tuberculous granulation tissue as well as by the attraction of the fibroblasts by the bionecrotic tissue.

Pinch, for example, uses the following radium doses:

In cases of ulcerated superficial tuberculosis cutis, 1 to 1½ hours full strength plaque, unscreened beta rays.

In indurated and infiltrated cases, full strength plaque, 0.1 mm lead, 2 to 3 hours beta and gamma rays.

In extreme cases of long standing, full strength plaque, 2 mm lead, 20 to 30 hours gamma rays.

Still more uncertain is the nature of the action of the rays in cases of vascular nevi. Pinch believes the action consists in producing proliferation of the endothelial lining of the vessels. This would mean a stimulating action and require small doses at frequent intervals. McKee is of the opinion that by radiation treatment "the mitosis is arrested, new vessels cease to form, and finally the poorly differentiated cells composing the vessels fail to be replaced and are absorbed." On account of the superficial location of the vessels beta rays are employed; when too strong a dose is not to be given, slight filtration is necessary in some cases. Very penetrating radiation, such as gamma or Roentgen radiation, does not produce favorable results and seems to affect the deeper layers unfavorably.

In the following methods of treatment a more or less damaging effect is to be produced on the cells and organs.

In cases of lymphatic and myologenous leukemia the object is to bring the abnormally high number of leucocytes down to normal. The treatment consists in raying the spleen, especially if the latter is enlarged, and the long bones, or in injecting radium salts or thorium.

The radiation is best carried out with Roentgen rays, the dose may be ½ or ⅓ of a unit skin dose. The use of radium applicators on the exterior is possible but impractical—at least the radiation must be carried out with a number of fields, strong filtration, and large focus dis-

tances. Intravenously ½ mg of thorium X may be injected ; the dose depends upon the blood picture, which must be continually controlled. With this dose the number of red corpuscles is usually increased.

Doses which impair functions have become of considerable importance in gynecology. In a series of diseases the arrest of the ovarian function leads to a disappearance of the symptoms.

To this class belong:

(1) Metropathia hoemorrhagica and the hemorrhages due to myomata.

In these cases the arrest of the ovarian function arrests the hemorrhages.

(2) Myomata.

Roentgen or radium castration produces, like the natural climacteric, a retrogression of the tumefaction.

(3) Osteomalacia.

By decreasing the activity of the ovaries by means of radium or Roentgen castration the softening of the bones can be arrested.

On the basis of these facts the radiation treatment of the above three diseases takes a simple course common to the three. The aim is to impair the functions of the follicles without damaging other tissues or affecting the general health of the patient. This can be done with simple means, since the ovaries are very sensitive to irradiation. A dose between ⅓ to ½ of a unit skin dose applied to the ovaries is sufficient to produce permanent castration. Somewhat smaller doses suffice to stop the hemorrhages. The treatment may be local if the position of the ovaries is normal or is known. In this case small Roentgen ray fields can be directed on each of the ovaries or radium may be introduced into the uterus. In

most cases by the application of 300 mghrs, the hemorrhages can be stopped with a single treatment. If they continue, the treatment can be repeated after a period of 2 to 4 months. The application of some 500 to 600 mghrs results in castration either at once or after one or two menstruations. More than this dose, 700 mghrs for example, are therefore not necessary for the treatment of myomata or osteomalacia.

If by the myomata the ovaries have been displaced from their natural position and their exact location cannot be accurately determined, it is best to ray with large ports of entry.

Whether the castration is carried out in one sitting or by repeated treatments used to be largely a question of technique. Nowadays castration with Roentgen rays or radium rays can conveniently be carried out in one sitting. This is desirable in cases of profuse hemorrhages; however, it is advantageous to distribute the castration over several sittings since in this way the climacteric symptoms are greatly mitigated.

Large, impairing doses play an important part in the therapy of carcinomata and sarcomata. All attempts made with small doses, just sufficient to stimulate the connective tissue, have failed. All investigators agree that doses much greater than the stimulating doses are required but there is still a difference of opinion on the magnitude of the dose. However, recent results obtained by a number of workers are gradually shedding more light on the subject.

Seitz and Wintz were the first to establish a so-called carcinoma dose based on accurate physical measurements of the applied doses and careful observations of the clinical results. This dose is given as 100-110% of their

unit skin dose and is said to be the most favorable dose for effecting the disappearance of a gynecological carcinoma (carcinoma of the uterus or breast). Kroenig and Friedrich have come to a similar conclusion. They assert that a dose 90% of their erythema dose is the most useful for the treatment of carcinoma. The erythema dose of Kroenig and Friedrich is 20-30% higher than the unit skin dose of Seitz and Wintz. Consequently the two carcinoma doses agree very well.

In the practice of deep therapy the doses given generally correspond fairly well with one another. With rays of weak penetration produced by apparatus of the older types a large number of fields are applied with appropriate doses, in one or more treatment series. With the hard rays available in the modern installations two methods are in use: either the so-called massive dose is given in a series of treatments over a period of a few days (Warnekross, Schmitz), or a large fraction of the dose is given at first and the rest later, a somewhat larger total energy being applied on account of the prolongation of the treatment (Meyer).

Recently experiments have been made with larger and with smaller doses: Perthes used doses up to 150% of the erythema dose, Juengling up to 125%, in some cases with soft rays up to 150%. Schmitz has used as high as 175% of the erythema dose in some cases to be mentioned later. On the other hand Opitz and others use doses which go down to 70 or 80% of the erythema dose.

Recently attention has been called by many authors to the fact that a carcinoma dose does not exist in the sense that every carcinoma can be made to retrogress by its application. This assertion is based on the experience that in spite of the application of this dose no

improvements resulted, as well as on the observation that even after the application of the strongest doses undamaged carcinoma cells can still be microscopically demonstrated; finally, on the fact that there are many kinds of carcinomata, which exhibit morphological, histological and genetic differences, as well as differences in their reaction to X rays and radium radiation. Thus a carcinoma of the basal cell type reacts very readily to irradiation while the cylindrical epithelial cell type is much less sensitive. The so-called gynecological carcinomata (uterus and breast) are in general much easier to treat than the surgical carcinomata (stomach and rectum). Of the gynecological forms, according to Warnekross, the soft glandular types (cervix, corpus uteris, ovaries) react more easily than the hard non-glandular cancroids (vagina, vulva). There is also a difference between a primary growth and a recurrent or metastatic formation; it is well known that no other carcinomata are as sensitive to radiation as the skin metastases of the breast carcinoma. According to Werner these have been made to retrogress with 30 to 50% of the unit skin dose. Finally, the result of the treatment depends a great deal on the general condition of the patient, it is a question of whether the patient can develop the necessary resistance against the carcinoma and whether or not he can overcome the toxins produced by the disintegration of the tumor. In very cachectic patients these powers are lacking, hence the utter hopelessness of success in these cases.

The modern conception of the carcinoma dose takes account of all these factors. It is based on the experimental fact that for many carcinoma cases a minimum dose can be stated, below which no favorable effect can generally be expected. This minimum dose, according

to Juengling, in the case of the first mentioned gynecological carcinomata lies between 90 and 100% of the unit skin dose; in the case of the last named carcinomata the dose is higher; in the case of skin metastases of breast carcinoma the dose it is lower. Even with these limitations the given value is not absolutely fixed; for example carcinomata in comparatively young people have been cured with much smaller doses, while carcinomata in senile and cachectic patients did not react favorably even with greater doses. Also in cases of laryngeal carcinomata, according to Juengling, the minimum dose is between 90 and 100% of the unit skin dose. According to Schmitz carcinomata of the basal cell type require about 90 per cent of his somewhat higher erythema dose; this corresponds very accurately to the statements of Juengling and others. According to the same author the minimum dose for a cylindrical epithelial carcinoma is to be found between 130 and 150% of his erythema dose, that for a carcinoma of the squamous epithelial type is still higher; Schmitz gives the value as 175%.

Besides the minimum dose the maximum dose can readily be given, which the seat of the carcinoma and the adjacent tissues will endure without heavy and permanent damage. Examples of such tolerance doses are the following: the tela subcutanea according to Juengling is more sensitive than the skin, 120% of a unit skin dose is quite certain to produce a chronic endurated edema, which appears as a belated injury after some months or a year; sometimes it appears with only 100%. According to Muehlmann and Mayer the adipose tissue beneath the skin of the abdomen is very sensitive to radiation. With 150% of a unit skin dose an atrophy appears. 100% is designated as a toxic dose.

The connective tissue and muscular tissue, according to Seitz and Wintz, tolerate very large doses, about 180%, without being greatly damaged.

The mucosa of the colon and of the bladder, according to Seitz and Wintz, have a tolerance dose of about 130% of a unit skin dose. Even with less than this dose irreparable damage results; with 160% an edema and ulceration of the bladder wall occurs; with 140 and 150% ulcers of the rectum occur. The mucosa of the small intestine is less sensitive than that of the colon by about 30% of a unit skin dose.

The values given for the ovaries by various authors agree very well. According to Friedrich and Kroenig, 20% of an erythema dose produces a temporary amenorrhea. According to Seitz and Wintz, 34% produces complete castration; according to Warnekross, 27% produces amenorrhoea; according to Schmitz, a dose of 6 or 12% of his erythema dose is stimulating, that is, it increases the functions; 15 to 22% decreases the functions, 25% to 40% is the castration dose.

The following doses for the testicles are stated by Schinz: above 34% oligonecrospermia occurs; with 60% total aspermatogenesis and azospermia; above 60% total castration.

For the treatment of carcinomata of the stomach a recent publication by Holfelder and Peiper is very significant. According to their investigations the cortex of the suprarenal glands is very sensitive to radiation, with as high as 60% of a unit skin dose no irreparable damage of the suprarenal glands of guinea pigs appears; larger doses more or less destroy the cortex, the lipoid content rapidly decreases and the animals die. In the human subject 100-110% of a unit skin dose produces

great damages, Addison's pigmentation and malaise for some months. In some cases after strong irradiation Addison's disease with fatal results occurs.

Tyler has called attention to the danger involved in intensive irradiation of the lungs. He observed fibrous changes following deep therapy treatment of breast and lung carcinomata. Pfahler states that there are two possibilities: (1) A malignant process becomes transformed into fibrous tissue under the influence of the irradiation. (2) An original fibrous process is stimulated to further growth.

A recent article by Juengling deals with carcinoma of the larynx. While irradiation with 100-120% of a unit skin dose, even if repeated after a period of one or three months, did not produce any particularly *early* reactions (three days) or *normal* reactions (three weeks), there did appear in a very large number of cases irreparable *belated* damage after 6, 12 or even 15 months which resulted in telangiectasies, sloughing, impossible deglutition, and finally death. At this stage an operation was no longer possible since there were adhesions to the adjacent tissues and cirrhoses. According to these authors therefore no dose stronger than 100% should be given and this dose cannot be repeated before three months have elapsed. Three irradiations can never be carried out. Also, according to Lehmann, with 110% the larynx can become gangrenous.

Similar danger of belated damages, according to both Juengling and Lehmann exists in joint cases. Larger doses than those absolutely necessary should not be given if belated effects are to be prevented. The doses whenever possible (tuberculous cases) should stay below 50%.

The bony tissue, according to Seitz and Wintz, and

many other authors, tolerates very large doses; cartilage is more sensitive. The periosteum is easily damaged by a destruction of its blood vessels.

Changes produced in the blood are more dependent on the total applied energy than on the energy density at any one point. Accordingly, a statement of the exact dose is difficult. In the case of intensive irradiation the number of the white as well as the number of the red corpuscles decreases greatly; the white corpuscles may almost entirely disappear after almost fatal doses have been applied. The coagulation time of the blood is decreased by the application of small doses; by the application of large doses it is considerably increased. Levin states that the lymphocytes are the most sensitive cells in the animal organism. Only when these are not damaged, a new formation of connective tissue, which is so important for the reception and displacement of malignant tissue, takes place.

The blood forming organs, the spleen, the bone, and the lymphatic glands are known to be very sensitive to large doses of Roentgen rays. Heinecke states that the lymphatic system is more affected by radiation than any other tissue; however, these organs regenerate relatively well, if the damage, either acute or chronic, does not exceed a certain limit.

According to Altmann and Wetterer, the various tissues may be placed in the following order of decreasing radio-sensitivity:

1. Normal tissue:

Lymphatic tissue, testicles, and ovaries.

Pathological tissue:

Leukemia, pseudoleukemia, psoriasic patches of recent origin, acute eczema.

2. Normal tissue:

The skin of the face in children, cartilage in children, mucous membrane.

Pathological tissue:

Chronic eczema, mycosis fungoides, lymphosarcoma, acne vulgaris, old psoriasic patches, lupus hypotrophicus, tuberculous lymphomata.

3. Skin, sudoriferous glands, sebaceous glands.

4. Connective tissue, muscle cartilage, bone.

According to Ewing the radio-sensitivity of the (malignant) neoplasms may be tabulated as follows in the order of decreasing sensitivity:

Lymphomatous group:

Cellular type of Hodgkin's disease,
Leukemia,
Lmyphosarcoma,
Thymic ulcers,
Myeloma;

Cellular carcinoma, anaplastic carcinoma, malignant carcinoma;

Myeloma, angioma, adenoma, adeno-carcinoma;

Basal cell carcinoma;

Hornifying squamous carcinoma;

The neurofibrosarcoma is the least sensitive.

The following table, taken from the same author, covers some of the structures of ectoplasmic origin:

Bladder mucosa,
Rectal mucosa,
Buccal mucosa,
Skin,
Brain tissue.

The latter is almost non-sensitive to irradiation.

On the basis of these facts a lower and an upper limit may be given for a number of defined carcinomata. According to Caspari and others the lower limit is fixed by the condition that the carcinoma is damaged and that the power of resistance of the body is both locally and generally mobilized. Caspari states that for this purpose a weak necrosis is necessary; this acts as a powerful stimulant on the fibroblasts, which by their proliferation continue the destruction in the tumor. The necrosis must not be so large that the resulting toxic effects permanently injure the organism. These conditions fix both the lower and the upper limit of the dose and determine *an optimum* carcinoma dose for a *particular* case (not *the* carcinoma dose in *general*. Its range may vary considerably. For an individual whose power of resistance is great a slight necrosis is sufficient to mobilize the fibroblasts; the body can also endure a much greater necrosis. On the other hand, a patient whose power of resistance is low requires a larger dose to stimulate the fibroblasts, but the general injurious effect produced is too great to be repaired by the body. This explains the ineffectiveness of Roentgen treatment in the case of highly cachectic patients.

The carcinoma dose for a basal cervix carcinoma exhibits a wide range. It begins with 90% of the unit skin dose; only with as high as 120 or 130% need damage of the surrounding organs be feared. Hence by a homogeneous irradiation of the pelvis with a dose lying in this range, favorable results may be produced in noncachectic cases. By the use of heterogeneous radiation much larger doses can be applied locally. Many thousand mghrs of radium can be applied through the cervical canal and a very heavy necrosis can be produced at

the focus of the carcinoma without seriously injuring the surrounding tissues. Hence even a cervix carcinoma of the cylindrical cell type can be successfully treated. The range of the dose in this case is not so large on account of the high minimum value of the dose.

In the case of an epithelioma of the skin, in spite of the high minimum dose, a carcinoma dose of wide latitude can be given since by the use of soft rays a small region of the skin can be rayed superficially very intensely without any danger to the underlying tissue or surrounding skin.

The range of the dose in the case of carcinoma of the larynx is very narrow according to recent researches. Nearly in every case 90% of the unit skin dose is necessary; 100% represents the upper limit. Since the range is so narrow, care must be taken to attain a good degree of homogeneity in the rayed region; otherwise some parts will receive too much and others too little.

Carcinoma of the stomach is also difficult to treat on account of the small range of the permissible dose, determined by the great sensitivity of the endocrine glands and the pancreas.

These few examples serve to illustrate what extremely different forms the problem of correct dosage may take for different cases. They show that a carcinoma dose does not exist. There can be no fixed procedure employing any one method of irradiation (Roentgen rays only, radium rays only, homogeneous irradiation, large fields, small fields). It is only by the correct combination of these means in a given case that all the difficulties can be overcome.

A discussion of the contraindications of irradiations is beyond the scope of this book.

The conditions in the case of sarcoma are still more complicated than those just discussed in the case of carcinoma.

Seitz and Wintz state the sarcoma dose as 60 to 70% of the unit skin dose. Kroenig and Friedrich determine the sarcoma dose as 50% of their erythema dose, hence practically the same dose. These values are very likely correct for sarcomata of the small round cell type and for sarcomata of the lymphatic system. They certainly do not hold for giant cell sarcomata and sarcomata of the bones.

According to Morson the following gradations in sensibility and reactions may be distinguished:

Spindle cell sarcomata are amenable to treatment if not growing in bone tissue;

Periostial and endostial sarcomata are more resistant;

Chronic sarcomata are sometimes improved;

With melanotic sarcomata the results are unfavorable.

Schmitz is of the opinion that:

Small round cell sarcomata require approximately 70%;
Small spindle cell and mixed cell sarcomata
approximately 130%;
Large spindle cell sarcomata approximately......175%;
Giant cell sarcomata approximately.............200%;
Lympho-adenoma, pseudo-leukemic lymphnodes,
according to Schmitz, require about......... 30%
of his erythema dose.

In his most recent articles Juengling calls attention to several important points:

The sarcoma doses are even more indefinite than the carcinoma doses; even apparently similar types react very differently to the same treatment.

Furthermore, the range of the favorable dose is remarkable; with very small and with large doses the same effects appear. Wintz also has recently called attention to this range of reaction. A prolongation of the dose matters much less according to Juengling in the case of sarcoma than it does with other malignancies.

The prognosis is not as unfavorable in the case of cachectic patients for sarcoma than for carcinoma. The effect seems to depend very little on the general condition of the patient.

On the other hand, with sarcomata much greater danger of metastases exists than with carcinomata; hence a more careful irradiation of the lymph vessels is necessary. Juengling states that in general a sarcoma dose is much less determined than a carcinoma dose even when all the factors which determine the dose are taken into account.

Lethal doses are never employed in deep therapy, if a lethal dose is defined as one which produces death of the entire organism.

Bacteria in general are very resistant and would require doses so great that the surrounding tissue would be totally destroyed.

However, it is important to have a knowledge of the doses which can damage the entire body or which can result in death. Of course all statements are very unaccurate since they can not take account of the many vari-

able biological factors, such as the region of application, the constitution of the patient, etc.

Wintz states that 6 or 7 a, that is, the application of 6 or 7 fields of the kind previously discussed produces a long continued injury to the patient. The ports of entry which are used in his technique are small, they amount to 48 sq. cm. (6 cm. $\times$ 8 cm.). Besides the penetrating power of the rays used is not great; only about 18% of the energy applied to the surface reaches a depth of 10 cm. With a field of this type about 1.5×10^6 e are applied. Since 6 or 7 fields are used, altogether as much energy as with a large field is applied, namely, about 10^7 e. Treatment of the uterus by means of three large fields or two large and two small fields supplies about three times this energy. The same total dose is therefore applied at one time, which in the Seitz and Wintz technique would be given in three series. Such an intensive irradiation is not easily endured on account of the large supply of energy. Hence the author recommends:

1) a procedure which applies a minimum of total energy;

2) a distribution of the treatment series over a period of one week, and

3) the previously mentioned means to reduce the radiation sickness.

Somewhat larger total doses fall into the range of the doses dangerous to life. The author is of the opinion that the application of more than four large fields in cases of extended carcinoma or general carcinomatosis imperils life in the majority of cases and therefore of necessity advises the distribution of the dose over sev-

eral series. Numerically the mentioned maximum dose which in some cases could be a fatal dose can be given as 5×10^7 e. Of course, a necrosis with fatal results can be produced by a much smaller dose if it is highly concentrated. We are not concerned with these cases here. The fatal dose of gamma radiation was investigated experimentally on animals by Lazarus and Barlow. They found that the gamma rays of 5 gram of radium element applied for 6 hrs. to a rat so injured the animal that it died in 42 hours. The corresponding time for rabbits was 9 to 10 hours. From these experiments no conclusions as to the corresponding dose for man can be drawn, first, on account of the great difference in size, and secondly, on account of the greater sensibility of man to Roentgen and radium rays. The author knows of a case where a 10 mg radium needle applied for 7 days, that is, an application of 1700 mghrs of beta and gamma rays, produced death of the patient inside of 7 days. This result, however, was caused less by the general action of the rays than by the terrible necrosis produced in the immediate neighborhood (2 cm radius) and by the severe inflammation of the adjacent tissue (7 cm radius) in the abdomen. If the needles are properly distributed, a dose of 1700 mghrs can be given without danger.

In the application of unfiltered emanation tubes which are to remain in the tumor Failla recommends a quantity no larger than 4 millicuries. This corresponds to an application of 533 mghrs. For larger tumors the dose should be about 0.5 millicuries per ccm. It is assumed that no large blood vessels or particularly sensitive organs are in the immediate neighborhood. Failla has also given permissible doses for injection of solutions of radioactive

substances (active deposit dissolved in physiological salt solution) into the veins or into the tumor. According to Failla it is advisable not to exceed 200 micrograms of radium element in 2 to 6 ccm of solution. With 250 micrograms severe toxic symptoms appear.

Gudzent states that doses of 500 micrograms of radium element and of one milligram of thorium X are close to a danger point. On the other hand Cameron, Viol and Proescher have administered intravenously up to 5 mg of radium bromide, that is, 2.7 mg of radium element in 2 ccm of normal salt solution without observing any bad effects; they consider, however, 50 to 100 micrograms of radium element as the correct and safe dose.

§ 2. Methods of treatment.

The preceding discussions give an idea of the size of the dose that is necessary in the majority of cases for relief or cure. Up to this point the problem of dosage has been largely biological or medicinal since it is important to know the location and extent of the diseased tissue, the nature of the disease, and the constitution of the patient. Once this is known the necessary step is to determine the best, that is, the least harmful and most economical method, which applies the correct dose in the specific case. The possibilities of the applications are legion as has been seen in the preceding chapter. Since a variety of methods are available: Roentgen or radium rays, soft as well as hard, to be applied locally or generally, or radioactive materials to be administered into the blood, by mouth or through the lungs.

In order to find the correct method of treatment it is necessary to pay special attention to three conditions:

1) The location of the region to be rayed: it may be superficial, central, or at a small depth within the tissue. The different locations require very different treatment and for each of the three possibilities a different method is appropriate.

2) The extent of the region to be treated: it may be localized, it may involve a large but bounded volume, or it may involve the entire body. The question whether local or homogeneous irradiation is required or whether a general treatment is necessary is decided by these conditions.

3) The magnitude of the dose. In the choice of a treatment technique it is very important to know whether small or large doses ought to be applied. In some cases the magnitude of the dose is limited by the available technique so that only an approximation of the correct dose is possible.

In the following, on the basis of these physical view points, the determination of the possible methods of irradiation is carried out for a number of cases occurring in practice:

(a) The conditions are simplest when a superficial region is to be rayed. Of course only soft rays are to be considered. Unfiltered rays or rays filtered with 1 mm of aluminum produced with a 20-25 cm (a 8-10 inch) spark gap, that is, about 60 to 80 K V, and with 20 to 25 cm focus skin distance. Only in cases where the infection extends to deeper layers a filtration of about 4 mm of aluminum is necessary. In radium treatment chiefly beta rays are used. For this purpose unfiltered surface applicators placed directly on the skin are most

suitable. For processes involving deeper layers small filtration and distances from a few millimeters up to 1 cm are appropriate. In this case an appropriate surface applicator can be made out of several radium needles. Particularly superficial diseases react better to unfiltered radium radiation since the latter delivers the least penetrating radiation. Lupus erythematosis belongs to this class, a disease which is not easily affected by Roentgen or gamma radiation but which responds very well to beta radiation. The conditions are the same for vascular nevi; in the treatment of the latter beta rays produce good results while Roentgen and gamma rays fail. In cases of nevus flammeus even beta radiation is too penetrating so that ultra violet rays or perhaps alpha radiation would be more favorable. However, in case of angioma cavernosum where the deeper vessels are involved, the somewhat harder gamma radiation of radium or Roentgen radiation is more effective.

In a number of dermatoses soft Roentgen radiation must be used, first, because the seat of the disease is in the superficial layers, and, secondly, because the disease frequently involves large surfaces. If the radiation were carried out with penetrating rays the deeper lying organs (blood, bone marrow, and spleen) would be exposed too much and injuries to the whole organism would be possible. In this category belong such dermatoses as psoriasis, eczema and lichen rubra. Ephitheliomata in their early stages can also be treated with soft Roentgen rays or with beta rays, particularly the squamous and cylindrical cell types which require very large doses. By limiting the field to the affected area and by not raying too deeply it is possible to give local massive doses without any danger of doing any damage.

In cases of deeper infiltration (epitheliomata of a pavement or tubular epithelial origin) of course, heavily filtered Roentgen radiation or gamma radiation of radium, applied from a distance of a few centimeters is appropriate. A number of diseases which have their seat at the hair follicles or in the deeper corium layers may also be treated with somewhat more strongly filtered radiation. For this class belong the dermatomycoses: trichophytosis, favus, tinea tonsurans. Acme vulgaris also must be treated with radiation filtered through about 4 mm. of aluminum, since the sebaceous glands are located at a depth of a few millimeters.

The doses to be used in superficial therapy range between the small doses, 1/10 of the normal skin dose or more, applied fractionally, in cases of eczema, psoriasis, keloids, mycosis, fungoides, chronic ulcers, etc., to large doses which are given in a few applications in cases of favus, verruca, clavus and epithelioma. In case of epithelioma a dose as high as 2 or 3 times the unit skin dose can be given, and this dose may even be repeated in two to four weeks.

An excellent summary of a well developed technique of Roentgen therapy has recently been published by Holzknecht in the form of a dosage table. While Holzknecht's deep therapy technique does not correspond to that employed in the United States since lower voltages, less filtration, and small focus skin distances are used, his superficial therapy technique is very similar to that in vogue in this country. The table gives a schematic but extremely useful outline of the most important treatment factors. In the following it is reproduced in a somewhat different form imposed by the lack of space.

Condition	gap cm	FSD cm	H	AL mm	Series-Interval Weeks	Number of Series	Unit Skin Dose H	Group
Epithelioma; **Verruca, Clavus**	27	18–35	8–15	3–4	4–8	1–2	9	I
Acne vulgaris	27	18–25	6	3–4	1–2	1–5	9	II
Bubo	27	18–25	6–8	3–4	2	1–2		
Condulomata acuminata	27	18–25	6–8	3–4	6–12	1–3		
Hyperhydrosis continua	27	18–25	6–8	3–4	6–12	2–3		
Hypertrichosis	27	18–25	6–8	3–4	12–16	3–5		
Carbuncle	27	18–25	6–8	3–4	....	1		
Rhinoscleroma	27	18–25	6–8	3–4	6–12	1–5		
Keloid	27	18–25	6–8	3–4	6–12	1–5		
Pseudoleukemia	27	18–25	6–8	3–4	6–12	1–5		
Tuberculous lymphoma	27	18–25	5–7	3–4	6–12	1–5		
Glandular tuberculosis	27	18–25	5–7	3–4	6–12	1–5		
Tuberculous sinovitis	27	18–25	5–7	3–4	6–12	1–5		
Alopecia areata	20–25	18–25	4–6	1–2	....	1	7	III
Congelation	20–25	18–25	4–6	1–2	4–6	1–2		
Erythema enduratum	20–25	18–25	4–6	1–2	4–6	1–5		
Favus	20–25	18–25	4–6	1–2	....	1		
Furunculosis	20–25	18–25	4–6	1–2	4–6	1–5		
Herpes tonsurans	20–25	18–25	4–6	1–2	....	1		
Lupus vulgaris	20–25	18–25	4–6	1–2	4–6	1–5		
Mykosis fungoides	20–25	18–25	4–6	1–2	4–6	1–5		
Phlegmons	20–25	18–25	4–6	1–2	4–6	1–5		
Scrophuloderm	20–25	18–25	4–6	1–2	4–6	1–5		
Congenital stridor	20–25	18–25	4–6	1–2	4–6	1–5		
Trichophytosis	20–25	18–25	4–6	1–2	....	1		
Tuberculosis of the mucosa	20–25	18–25	4–6	1–2	4–6	1–5		
Lupus exedens	20–25	18–25	4–6	1–2	4–6	1–5		
Dermatitis capillaris capillitii	20–25	18–40	3	1	2–3	1–2	5	IV
Chronic eczema	20–25	18–40	2–3	05–1	2–3	1–2		
Lichen planus	20–25	18–40	2–3	05–1	2–3	1–2		
Pityriasis rosea	20–25	18–40	2–3	05–1	2–3	1–2		
Pruritus	20–25	18–40	2–3	05–1	2–3	1–2		
Psoriasis	20–25	18–40	2–3	05–1	2–3	1–2		

Column 1 gives the disease to be treated. Heavy type denotes those in which Roentgen irradiation is, at the present stage of the science, the treatment of choice . . . ; those which experience has shown to be very favorably affected by X ray are shown in italics . . . ; ordinary

type denotes those in which Roentgen treatment has given favorable indications although other methods of treatment may be used. . . .

Column 2 gives the voltage in terms of the spark gap in centimeters between points.

Column 3 gives the focus skin distance in centimeters. When extensive irradiation becomes necessary as in the last group (IV), larger focus skin distances are sometimes necessary to insure surface homogeneity; according to Holzknecht the distance should be double the size of the field if a plane surface is to be uniformly rayed from a single point. In the irradiation of very large surfaces, of the head in particular, so-called total irradiations in which boundaries of the field are not fixed by absorbing materials become necessary and the focus distance can be somewhat smaller.

Column 4 gives an idea of the energy to be applied at the surface. In the first and second groups, that is, with fairly strongly filtered radiation, 9 H corresponds to a unit skin dose. In the third group (1-2 mm Al) 7 H corresponds to the same dose. In the last group the unit skin dose can be assumed equal to 5 H. The H values give the size of the single dose, the effect of varying hardness being taken into account.

Column 5 gives the interval between two treatment series. Holzknecht states that six weeks are required for the recovery of the epithelium when an erythema dose has been applied. When more than two series have been administered, the recovery of the capillaries must also be considered; this requires some three months, if belated effects such as atrophy of the skin, telangectasies. and ulceration are to be avoided. If very soft radiation is

used, the periods between series may be of shorter duration.

Column 7 gives the number of series to be applied. The number of series should not be too large; the first series produces the major part of the results; additional series, after a certain limit has been reached, is apt to be more harmful than beneficial. One series may be given as a precautionary measure after the cure of the disease has been effected. We are concerned here with treatment series, not single treatments, because in extensive dermatoses several fields must be used and also because the treatment of a single field may be extended over several sittings.

The basic idea of the table is the classification of the diseases into four groups, which are to be treated with doses of different strengths and with radiations of different degrees of hardness. These two factors: dose and hardness, i.e., quantity and quality, determine to a great extent both the time intervals between series and the number of series, so that only a small variation in these factors is to be expected.

(b) The second physical group consists of those cases in which the diseased area is situated at a depth. The technique used in these cases is radically different from that used in the superficial group: it is characterized by the use of very hard rays applied through several ports of entry. Frequently radium may be used in addition, or alone.

The development of deep Roentgen therapy began with the application of many small fields which were concentrated on the region to be rayed. This method was worked out chiefly by Seitz and Wintz in the Frauenklinik at Erlangen. The large field method, which con-

sisted chiefly in the application of four fields to cases of extended carcinoma of the uterus, was developed by Dessauer and Warnekross on the basis of the phenomena of scattered radiation. For a time these two schools opposed one another, and each one emphasized the advantages of their method. Recently, however, each method has found its own field of application depending on whether a localized or a homogeneous effect is desired. In fact it is an important question whether a very limited volume is to be given a large dose or whether an extended volume is to be treated with a smaller dose distributed as uniformly as possible. From the standpoint of the local or homogeneous treatment a few examples of deep X ray therapy will now be considered:

Seitz and Wintz in the development of the cross fire method considered the treatment of uterine carcinomata under the head of localized treatment. Next when they found that the broad ligaments required an irradiation equally as strong as the primary carcinomata in order to cure or prevent recurrent carcinoma, they added a localized treatment of the parametral regions.

The treatment factors of Seitz and Wintz were 170 K V, 2-3 M A, 0.5 mm zinc filtration, 23 cm focus skin distance, 6 cm $\times$ 8 cm port of entry or an anatomical cone, a quadrant of about 100 sq cm in area. With these factors the depth dose was 18%. With the application of a unit skin dose to the skin, the use of 6 or 7 fields, and with the aid of compression, a Seitz and Wintz carcinoma dose could be applied to the interior. Compression is practical when small fields are used, especially in the region of the abdomen; it shortens the path of the rays by several centimeters and makes the tissues bloodless. With large fields compression has little effect, since

it displaces the part to be rayed. An irradiation of the parametral regions if necessary is carried out later: After a period of 6 weeks three ventral fields and three dorsal fields similar to those used in the uterus treatment are employed and the radiation concentrated on the right parametrium; after another interval of 8 weeks the left parametrium is treated. The advantages of this method are, that it spares the patient, that in one series only a comparatively small volume of tissue and blood is rayed, and that between the series the patient is given a long time for reaction and recovery. The difficulties involved in this method are that the path of the beam and the extent of the region subjected to the rays must be known very accurately and that a great deal of skill is required to concentrate the rays correctly on the desired region. The disadvantages are, perhaps, that portions of the cancer tissue are left for some time without being treated and that other parts do not receive a sufficient dose. However, in the light of our present knowledge these points will not cause a great deal of anxiety. The accurate determination of the energy distribution in the interior when this method is used is not easy. The distribution depends to a high degree on variable factors, in particular on the distance between adjacent fields. In general the action of as many as six or seven fields is not as localized as one is inclined to believe. In particular due to an overlapping of the beam, areas of high energy concentration may easily occur outside of the region to be rayed.

In the treatment of the uterus Seitz and Wintz have also enlisted the aid of radium, insuring an increased localized action on the focus of the carcinoma.

The sterilization of the ovaries in hemorrhages, myo-

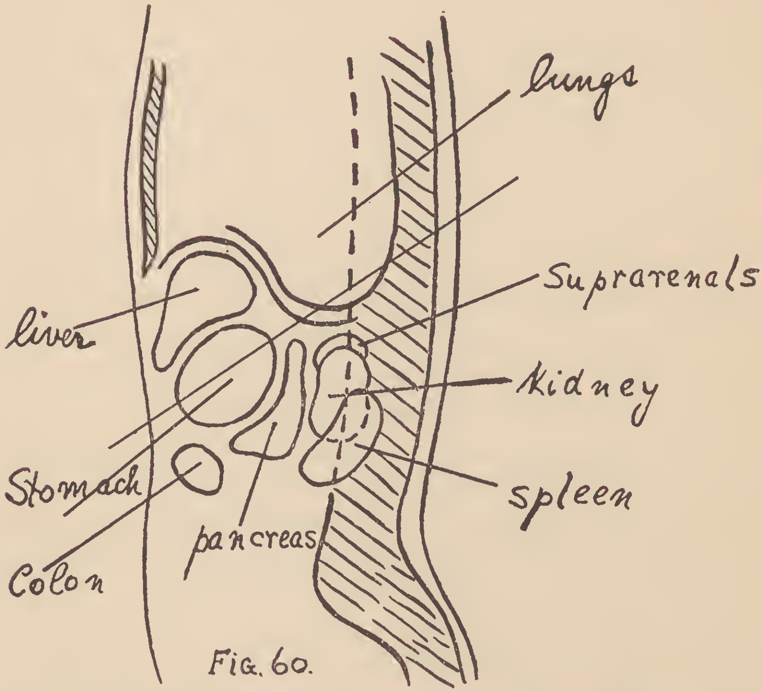
mata, osteomalacia is often carried out with small fields or by the application of radium through the uterine cavity. This method is always appropriate when the exact location of the ovaries is known and their distance from the radium source is not too great. The treatment is not difficult since only small doses are required.

While in these cases localized irradiation has been frequently displaced by homogeneous irradiation, in other cases the former has proved its superiority.

This is true for example, for many cases of carcinoma of the stomach. According to Holfelder and Peiper the organs adjacent to the stomach are very radiosensitive. The suprarenal glands and the spleen can endure only small doses without damage. A strong irradiation of these glands as well as of the pancreas and the liver would result in aggravating the radiation sickness, which, however, is to be avoided in the treatment of the stomach. Homogeneous irradiation of the region of the stomach has been frequently carried out, but in general without prompt results and with serious injury to the patient; local irradiation by means of very carefully selected small fields insures (according to Holfelder's experience) much better results. Holfelder states that all the fields cannot be given at right angles to the axis of the body. The best arrangement is that illustrated by the following diagram (Figure 60).

The field which supplies the greatest intensity is best given obliquely from below to the affected part of the stomach, its prolongation then neither strikes the spleen nor the suprarenal glands. Often two other fields with a very favorable depth dose can be given from the left and right side, at right angles to the axis of the body and as close to the front as possible. A less effective dorsal

field can be given from above through the lower part of the lungs. All fields then lie in an oblique section through the body, the plane of which passes anteriorly below the

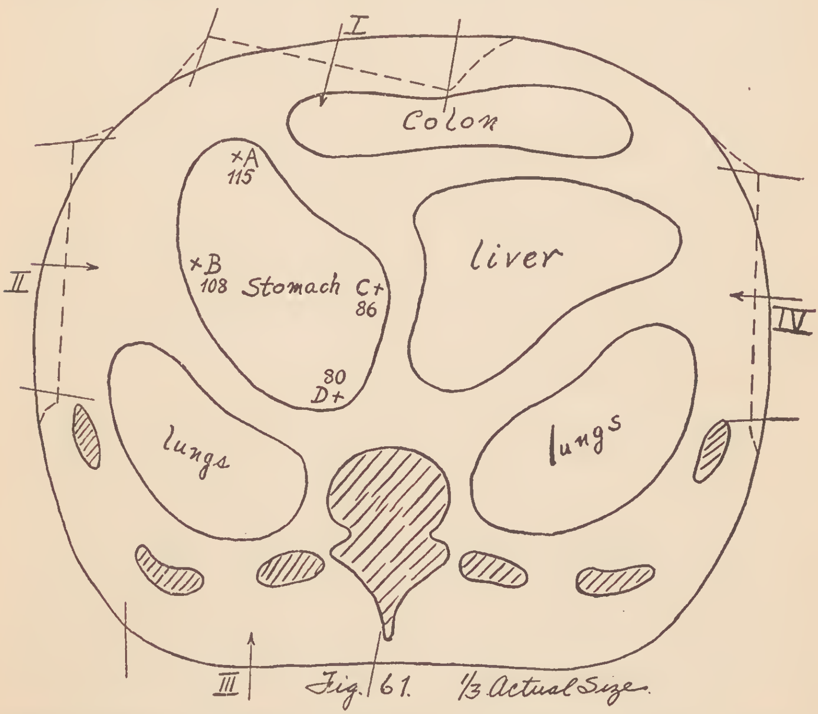


Oblique Ports of Entry in Treatment of the Stomach.

stomach and posteriorly above the stomach. The distribution in this plane can be easily determined with the help of the charts.

Figure 61 exhibits the results, which were obtained by the method previously discussed. The anterior-posterior diameter appears elongated because the cross-section passes obliquely through the body. For the same reason the section passes through the lungs at the rear, through the stomach and the liver at the center, and pos-

sibly through the colon in front. The irradiation is carried out with 4 fields of the type previously discussed; each field is about 10 cm × 10 cm and light compression is used. The skin dose is reduced to a total of 100%. The intensity corresponding t o4 points has been calculated. The values show that three fields alone supply sufficient



Cross Section of Patient, Treatment of Stomach, 4 Ports of Entry.
200 KV.
¾ MM Cu.
50 CM F. S. D.

intensity to the greater curvature of the stomach; it is more difficult to supply enough energy to the more centrally located regions (lesser curvature). Even with 4 fields the intensity is still insufficient; however, another

field applied from the front may be added to make up the necessary energy.

The irradiation of stomach ulcers can be carried out *similarly* except that much smaller doses are required; so that two fields per series and a low skin dose are sufficient.

In cases of cancer of the oesophagus fields at right angles can be employed since the beams do not strike very susceptible organs. A localized treatment with small fields should be carried out in order that too great an amount of energy is not applied to the lungs. In cases of cancer of the oesophagus combined Roentgen ray and radium treatment is often favorable.

A further application of localized irradiation is found in the tumors of the hypophysis. On account of its central location in the head, the hypophysis can easily be reached from various ports of entry. In addition, radium can be applied through the nose.

Carcinomata of the bladder, of the rectum and of the prostate are often treated locally by means of radium. The following possibilities of radium application exist:

(1) A capillary tube may be placed in the center of the bladder distended with water, or in the center of the rectum. In the latter case the radium capsule may be surrounded by an amber or bakelite sheath in order to secure its central position. A total of 1,000 milligram-hours applied in fractional doses may be used. This method makes a fairly uniform irradiation of the entire inner wall possible, with some penetration.

(2) Lightly filtered or unfiltered preparations may be applied locally to the affected region. Strong reactions may be produced at the surface, some 500 milligram-hours being applied.

(3) The tumor can be made accessible by means of

an operation and the needles or emanation tubes can be inserted directly into the tumor.

In contrast to localized irradiation let us consider the homogeneous irradiation of extended regions. The latter method must be used in cases of carcinomata of abdominal organs, particularly of the uterus and adnexa, as well as in metastases in the liver; the entire liver should receive a homogeneous irradiation if in any way possible.

The advantages of homogeneous irradiation are as follows:

(a) Uterus carcinomata, especially cervix carcinomata spread laterally very rapidly to the parametric regions and upward along the lymph vessels to the liver. Hence it is very appropriate to ray the entire environment of the primarily involved region or, as the case demands, to ray the entire pelvis and the lymph vessels, as high up as the umbilicus.

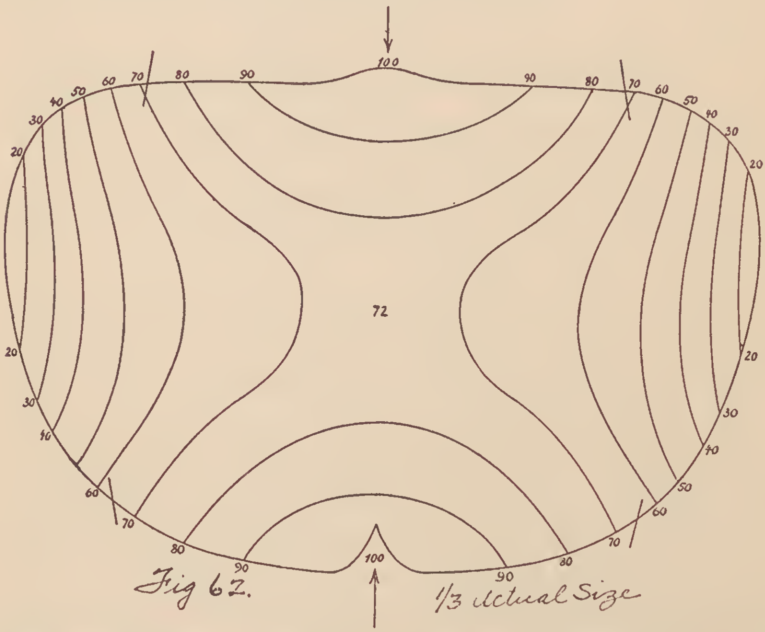
(b) The organs lying in the region to be rayed in this case are not so sensitive that the correct application of the required dose involves any danger.

(c) With large fields the required dose can be applied with a greater degree of accuracy than was the case for small fields; overexposure produced by overlapping of the beams or underexposure produced by erroneous localization or by an inadequate aiming of the beams, can more easily be avoided.

The large field method at the present time employs the following treatment factors:

200 K V;
½-1 mm of copper;
30-60 cm focus skin distance;
100 sq cm-400 sq cm size of field;
2, 3, or 4 large fields.

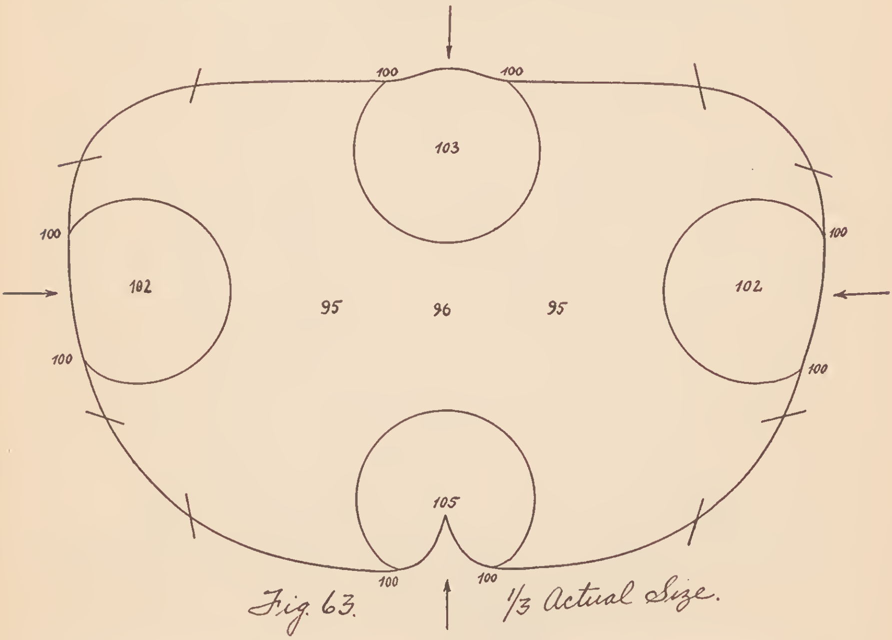
When two fields are used one is applied anteriorly and the other posteriorly, each being 20 cm × 20 cm; when three fields are used one large field is given anteriorly and two obliquely from the dorsal side; when 4 fields are used two large square fields are given one anteriorly, one posteriorly, and two rectangular lateral fields are given at right angles to the others. The most homogeneous distribution is obtained in the last case. This is shown by the following illustrative cases:



Distribution Obtained with 2 Ports of Entry, Anterior, Posterior (Abdomen).
200 KV.
¾ MM Cu.
50 CM F. S. D.

Figure 62 shows the isodosage lines in a cross section of the body. If an energy of 100% is applied to the surface in the case of the two large fields the interior receives

about 72%, in general therefore an insufficient dose. The region of the broad ligaments receives only about 70%. Laterally, the energy decreases very rapidly.

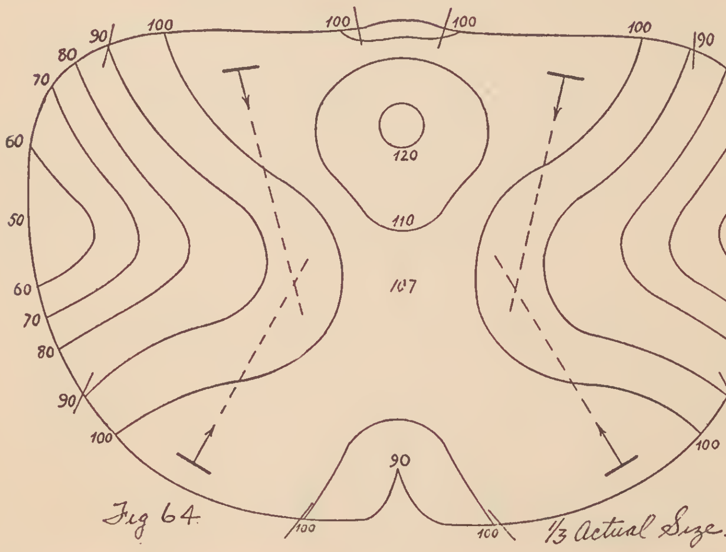


Distribution Obtained with 4 Ports of Entry, Rectangulary (Abdomen).
200 KV.
¾ MM Cu.
50 CM F. S. D.

Figure 63 shows the distribution obtained with 4 fields; it is almost homogeneous. At every port of entry the intensity increases slightly during the first few centimeters, in the interior, the intensity decreases to 95%; hence an intensity sufficient for most cases is produced in the interior.

While in the case just discussed the fields were at right angles (anterior, posterior, right, left), another

arrangement often employed with smaller fields, 10 × 10 cm, is shown in Figure 64.



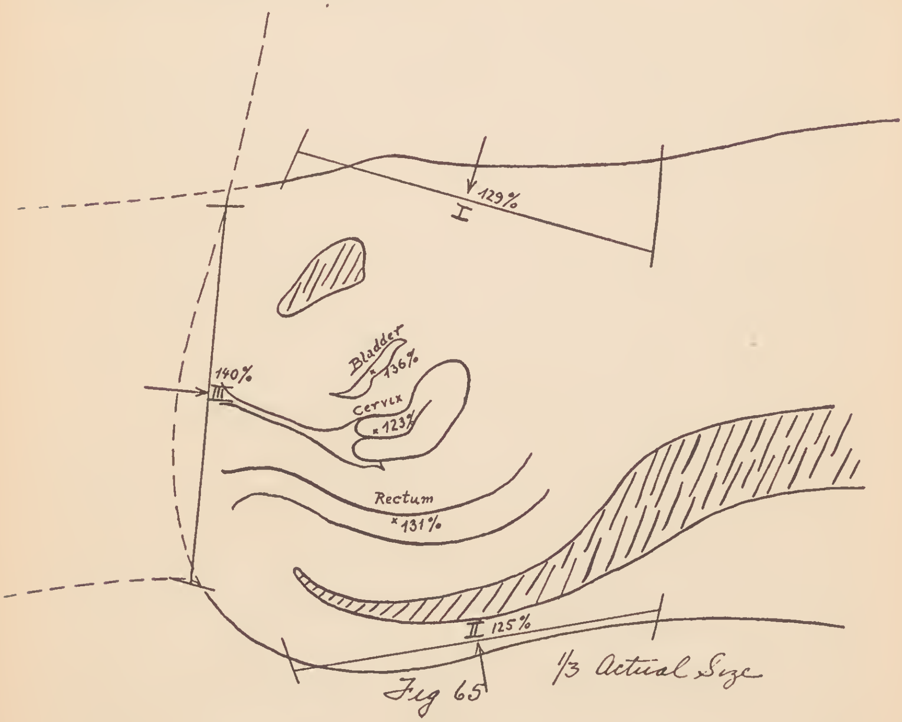
Distribution Obtained with 4 Small Ports of Entry and Compression (Abdomen).
200 KV.
3/4 MM Cu.
50 CM F. S. D.

The beams pass obliquely through the body, the fields being applied anteriorly and posteriorly. By means of compression the distance is decreased by 1 or 2 centimeters, the rays are not directed at the cervix but toward the broad ligaments. The distribution is less homogeneous than in the preceding case, the cervix received 107%, the broad ligaments only 95%, and the vicinity of the bladder 120%.

Surprising results are often obtained as shown in this particular instance—the extreme heterogeneity found in this case would hardly be anticipated. If all the central

rays are directed toward the cervix, the distribution becomes still more heterogeneous.

Another possible arrangement for treating the abdomen is shown in Figure 65.



Three Medium Sized Fields (Abdomen).
200 KV.
¾ MM Cu.
50 CM F. S. D.

Three medium sized fields are applied at such angles that the central rays make nearly equal angles (120°) with each other. If the patient is thin, approximately 100% is supplied to points in the interior. However, due to lack of compression it is not possible to attain a very

uniform distribution, sometimes an overexposure of the vulva results. This method give a distribution well suited for the treatment of cancers of the vagina, of the prostate, and deep seated carcinomata of the rectum. In cases of carcinomata well up in the rectum the treatment is best carried out with 4 fields.

The combination of radium and Roentgen radiation is often advisable, particularly in the following cases:

(a) When the patient is very thick so that it is difficult to produce sufficient intensity in the interior.

(b) When the cancer is of such a type (cylindrical cell carcinoma), that it is desirable to apply a larger dosage locally than the surrounding organs can endure.

In both these cases the dose is limited to the maximum dose tolerated by the bladder and the rectum.

In estimating the relative magnitudes of the doses to be applied, two facts must be kept in mind. First, if a relatively strong radium dose or radium alone is applied, the local reaction of the cervix or uterus predominates; and, second, with a relatively large Roentgen dose the greatest homogeneity is in the region of the broad ligaments. If radium alone were used, the broad ligaments in most cases would not receive sufficient energy, since they are at a much larger distance from the source than the bladder or the rectum. The maximum dose, if radium alone is applied, is from 4000-5000 mghrs when the distance of the source from the bladder and rectum is 1 inch. Only in cases of strong infiltrating carcinomata of the cervix where the distance to the bladder and rectum is great, can larger doses be given. In extremely unfavorable cases the bladder and rectum can be partially shielded by means of protective lead screens some 3 mm in thickness.

Roentgen and radium radiation should never be applied simultaneously. One reason is that the radium capsule screens a part of the region to be rayed in one direction and sends out secondary rays in the other. Under- or over-exposure can easily result. A second reason is that the simultaneous combination of several large Roentgen ray fields and radium treatment is more than the patient can withstand. A distribution of the dose over a period of time is better than a concentrated irradiation from the standpoint of the general effect on the patient.

The accurate dosage necessary in cases of carcinoma of the uterus requires individual treatment and a very careful estimation, either by measurement or from distribution charts, of the Roentgen or radium energy to be applied. In order to facilitate this procedure an attempt has been made in the following table to give a simple scheme for the irradiation of this organ.

The table provides for combined Roentgen and radium treatment, it gives the number of fields and the number of milligram-hours as a function of the anterior-posterior diameter of the patient. Two possibilities are left open to choice: The greater part of the energy may be applied by means of Roentgen radiation and a small amount of radium energy added, or the major portion of the energy may be applied with radium and a small amount of Roentgen radiation added. The first method is advisable when the carcinoma has been cut away and the broad ligaments and lymph channels require large doses; the second method is to be preferred in cases of beginning carcinomata or of epitheliomata of the cervix, when a strong local action is desired at the focus of the tumor. In cases of extensive involvement of the cervix (cauliflower

growths) it is advisable to distribute the dose over the tumor by imbedding needles or emanation tubes.

Anterior-Posterior Diameter	X rays, number of fields	Time reduction for each field	Radium, 1½ mm brass filtration
10 cm	2	30%	0-1000 mghrs
15 cm	2	18%	1000-2000 mghrs
	3	30%	500-1000 mghrs
20 cm	2	11%	2000-3000 mghrs
	3	25%	1000-2000 mghrs
	4	25%	1000-1500 mghrs
25 cm	2	7%	3000-4000 mghrs
	3	20%	2000-3000 mghrs
	4	20%	1000-2000 mghrs
30 cm and more	3	10%	3000-4000 mghrs
	4	10%	2000-3000 mghrs
	5	10%	1000-2000 mghrs

For bladder, rectum, and prostate the number of fields is about the same.

In these cases Roentgen ray and radium treatment can also be combined according to the method discussed above.

A further field of application of homogeneous irradiation, according to Juengling and others, is the treatment of tuberculosis of the joints and lungs. The dosage presents no difficulties since only small doses need be applied.

Homogeneous irradiation of the joints can be accomplished according to Juengling by building a pasteboard box around the region to be treated and filling the box with bolus alba. Also, if water bags are superposed, the

raying can be carried out from three or four sides without the danger of the overlapping of beams. An approximately homogeneous irradiation can be carried out with thin patients by means of one anterior and one posterior field; with thick patients 4 fields can be given obliquely.

(c) A third physical class of areas to be rayed is characterized by regions of intermediate depth. On the one hand, the depth of the area is too large to permit of treatment by means of a single field and, on the other hand, the position of the area is not central, as in the preceding cases (uterus, prostate, stomach, liver, hypophysis, etc.), so that the region is not well adapted to the cross fire method. The treatment of these cases therefore involves difficulties. The following methods have been developed and used in these cases:

(1) The irradiation can be carried out with one field and very penetrating radiation, heavily filtered Roentgen rays and a focus skin distance up to 1 meter being used. Besides, a slight overdosage is applied to the surface, so that in spite of the absorption in the surface layers a sufficient intensity reaches the interior.

This method has been tried by Seitz and Wintz on carcinomata of the vulva; with a focus distance of 1 meter a strong erythema dose is applied to the surface of the vulva; the dosage must be carried out very carefully since overexposure would result in an extremely painful and difficultly healing inflammation. Cancer nodules in the breasts, as well as the axillary glands in cases of breast carcinomata, have been treated by the same method. The results were not very satisfactory. The method has been abandoned therefore or combined with others. The single field is still retained in those cases where the desired dose is of such a magnitude that it may be applied with-

out resorting to large focus distances and overexposure. These conditions are fulfilled when the spleen or the thymus gland are to be given a stimulating dose since only $^1/_{10}$ to $1/5$ of a unit skin dose is required. The single field is also applicable to deep seated cancroids in the skin, since in these cases large doses at the surface are appropriate; Perthes applies a dose strong enough to cause vesication; Juengling applies up to 150% of a unit skin dose with slightly filtered rays (1-3 mm aluminum), and up to 130% of a unit skin dose with a $1/2$ mm zinc filter.

The treatment of carcinomata of the tongue from the surface by means of gamma rays and with a strong overexposure of the surface also belongs under this head.

(2) The second method consists in artificially placing the affected region at a depth at which cross fire irradiation can be carried out from several sides. This method is always advisable when a homogeneous irradiation is desirable or at least is not injurious.

These conditions are fulfilled in carcinomata of the vulva. The region of the vulva can easily be rayed homogeneously when the patient is rayed in a distended recumbent position with the legs close together. An anterior, a posterior, and possibly two lateral fields are applied.

The adjustment is made so that the central ray strikes a little above the vulva. In order to avoid an overexposure due to the addition of direct and scattered radiation in the region of the nates, a paraffine wedge is inserted which absorbs the direct radiation.

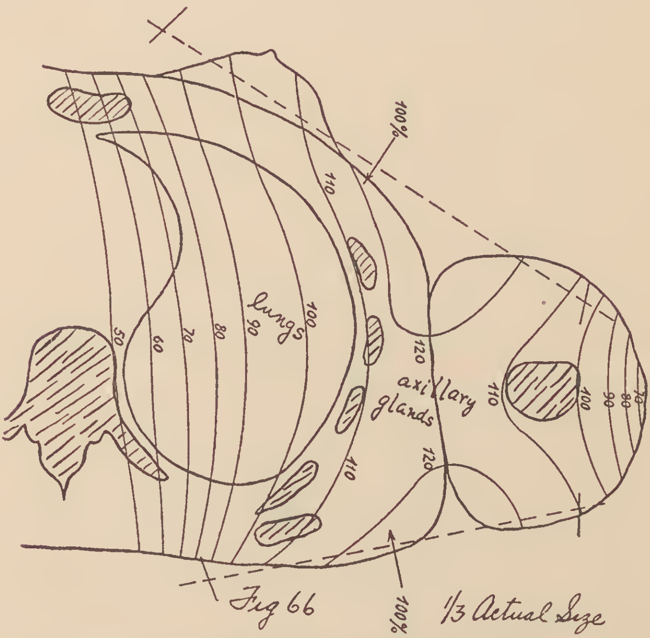
The conditions are the same in the irradiation of the axilla. If the arm is placed close to the body, a homogeneous irradiation can be obtained by means of two fields one anteriorly, one posteriorly. In special cases a third

field can be added. According to Dessauer a field given through the arm is suitable; however, in the author's opinion a field applied through the shoulder is more appropriate, since it is directed toward axillary glands and moreover also strikes the supraclavicular glands. Dessauer has proposed to ray carcinomata of the breast homogeneously as a whole (breast, axillary, infra and supraclavicular glands) by means of large fields. A large anterior field extends over the breast and infraclavicular glands; a smaller field is applied from the rear toward the axilla, while a field from above strikes the supraclavicular glands and the axilla. The addition of these fields produces a high intensity in the interior. A decrease of intensity from the surface to the interior of the breast can only be avoided if a large dorsal field is applied, however, by this means the lungs are easily overexposed; it is particularly dangerous to give the same treatment to both the right and left half of the body since burns in the lungs may result. In this case only small dorsal fields should be applied locally toward the axilla.

Figure 66 shows a cross section through the thorax somewhat below the axilla and slightly above the breast. Two fields each with an intensity of 100% at the surface are given. The isodosage lines show the intensity distribution. Toward the interior the intensity is fairly homogeneous but falls off from right to left. Due to this fact the tissue of the lungs is somewhat protected.

If this method of treatment does not apply sufficient energy to the axillary glands, a radium tube can be introduced into the axilla. If the beta rays are totally absorbed and the tube is placed two centimeters from the surface of the skin, a certain depth action can be produced, which adds to the Roentgen radiation.

Also in the radiation treatment of carcinomata of the larynx we are dealing with the irradiation of a region which lies only a short distance beneath the surface. On account of the limited permissible range of the dose, which is from 90 to 100% of a unit skin dose, Holfelder states that a homogeneous irradiation is appropriate. Moreover, there is little danger of injuring neighboring organs.



Breast Carcinoma, 2 Ports of Entry, Thorax.
200 KV.
¾ MM Cu.
50 CM F. S. D.

Homogeneous irradiation in this case presents some difficulty because there is danger of overlapping of the beams. Hence in this case the use of water bags is advisable, at least for the two oblique fields. A third field can

be applied from the rear. On account of the small diameter of the region rayed only about half of an erythema dose can be applied to each surface.

Figure 67 shows a treatment case in which a homogeneous irradiation of the region of the larynx is

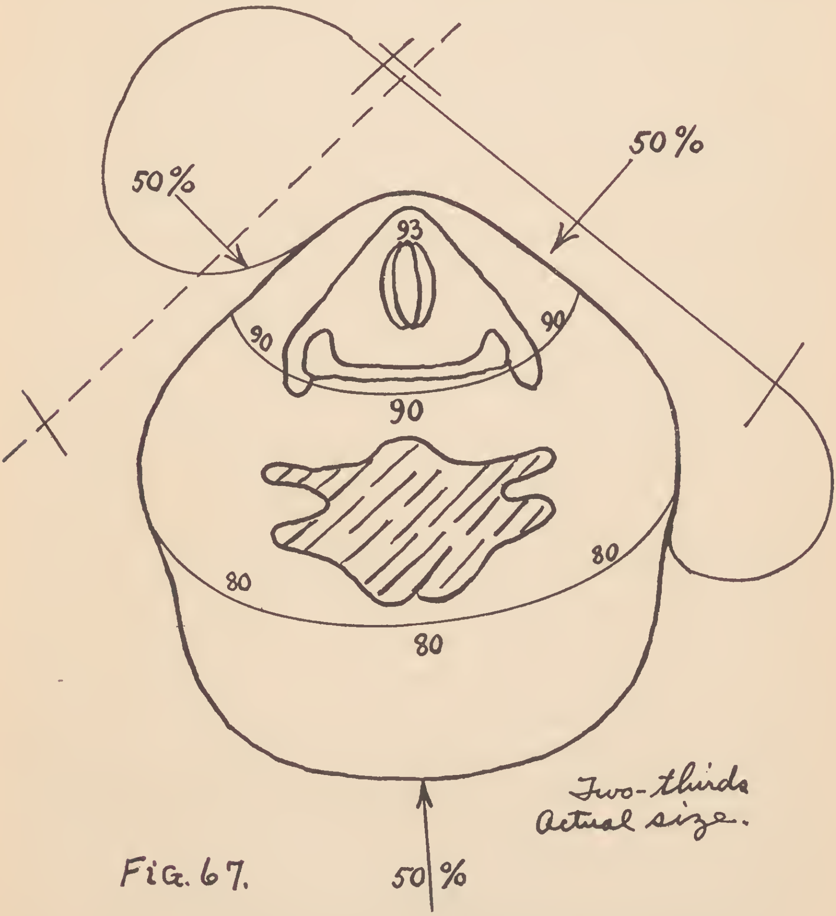


Fig. 67.

Cancer of Larynx. Treatment with Superposed Layers.
200 KV.
¾ MM Cu.
50 CM F.S.D.

attained. A superficial layer of 1 cm of water is used and three fields at each of which 50% of a unit skin dose is applied. A uniform application of from 90 to 100% is not difficult by this method.

(3) Since the two methods just described are not always adequate for producing sufficient intensity at a small depth, due to the fact that either the overlying tissue or the surrounding tissue receives too strong a dose, attempts have been made to produce a local action by imbedding the source of radiation in the interior of the affected region. For this purpose radium needles are placed in the tumor at easily calculated distances apart and allowed to remain until an application of 100 mghrs has been made, or emanation tubes are placed in the tumor by means of an obtuberator and allowed to remain there since they slowly lose their activity. The number of ampules and the number of millicurie-hours can be deduced from preceding considerations. This method is best suited to tumors which are located at a small depth; hence it is applicable to carcinomata of the breast and metastases of the same, as well as to carcinomata of the tongue, lips, and cheeks, as soon as these penetrate to deeper layers. In a much larger number of cases than are now so treated, radium needles or emanation tubes should be inserted at the time of operation, when an exploratory operation discloses the futility of surgical intervention. The method can also be used for treating tumors at a greater depth if they can be made accessible. This is often possible in cases of sarcomata as well as carcinomata of the prostate and of the stomach.

The injection of radioactive solutions cannot be used for the local treatment of tumors since the radioactive substances are rapidly distributed over the whole body

and are partially deposited in the blood forming organs.

(d) A fourth group are those cases which require a general treatment of the whole body.

Of course, a general treatment can be carried out only with small doses. Large doses, such as those necessary in the treatment of carcinomata, would be fatal if applied to the whole body. On the other hand, small doses, which stimulate metabolism, lower the blood pressure, and accelerate secretion, can easily be tolerated by the body. The general treatment, therefore, finds its chief application in internal medicine in the treatment of such conditions, as gout, arthritis, myalgia, anaemia, leukemia, Hodgkins disease, constipation, etc.

The treatment can be carried out by any method which sends a small stimulating energy through the whole body. Best suited is the administering of radioactive substances internally; this can be done by:

Intravenous injection,

Drinking or swallowing of radioactive water or pills,

Inhaling of emanation.

The irradiation of the whole body with hard Roentgen radiation should also produce similar effects; however, so far no systematic experiments have been conducted along this line.

The general treatment of the whole body with large doses would seem appropriate in cases of general carcinomatosis, as well as sarcoma of the lymphatic system, or sarcoma metastases. However, since the body could not endure such an irradiation, the treatment can only be carried out in parts by dividing the body up into a number of sections and treating these separately. For example, in cases of general carcinomatosis, first the involved skin areas can be treated with soft rays, then the deep seated

carcinomata by cross fire methods, and, finally, the swollen lymphatic glands can be subjected to strong radiation. Of course, a cure is not possible but the disease can be held in check for some time by this method.

(e) Many cases of Roentgen or radium treatment present must greater difficulties than those discussed in the preceding examples. In these cases a combination of the methods described is desirable. The best known example of this class is the combination of intensive local treatment with homogeneous irradiation of the adjacent regions.

In this category belongs the most commonly used and already described method of uterus treatment, in which the primary carcinoma is attacked by intense radium irradiation while the Roentgen irradiation serves to reduce recurrent growths or to prevent their formation. The treatment of carcinoma of the rectum should be carried out in a similar manner; besides a strong irradiation of the seat of the cancer, a homogeneous irradiation of the inguinal glands ought to be carried out. Under this head also belongs the combination treatment of epitheliomata of the tongue, of the lips, and of the cheeks, that is to say the localized treatment of the growth proper with very intense doses in conjunction with the homogeneous irradiation of the involved lymphatic tissues with small doses. The treatment of sarcoma is very similar; in addition to the local treatment of the tumor proper, the surrounding region should be safeguarded against swelling and metastases by appropriate treatment.

Finally, all methods which tend to increase the power of resistance of the patient and to improve the general health of the patient must be combined with radiation treatment—however, this subject is beyond the scope of this book.

§ 3. Case record blank.

A case record blank is appended, which gives a very comprehensive view of the treatment sequence and furthermore serves as a record.

Patient.......................**Age**........

Disease, etc.............................

Constants	**Date**	**Area, cm²**	**Application MA min / Mg hrs**	**Distribution**				**Reaction**
				Area	**X ray**	**Radium**	**Total**	
(200) **KV**.....	(Jan.) (2)...	(Ant. 20²)..	(400)	**Skin**......	(100)	(—)	(100)	(Normal Erythema
(5) **MA**.....	(3)...	(Post. 20²)..	(375)	**Tumor**....	(90)	(∞)	(∞)	Tumor reduced
(¾) **mm Cu**...	(5)...	(Rt. 10x15).	(450)	**Bowels**....	(90)	(40)	(130)	Bladder irritated)
(50) **cm FSD**..	(7)...	(Lft. 10x10).	(450)	**Broad Ligaments.**	(86)	(15)	(101)	
	(9)...	(Uterus)....	(1500)	**Axillary glands**...	(—)			
(50) **mg**..... (1.5) **mm (brass)** (0) **cm Distance**	(Mar.) (5)	Intravenously....	2ccm					
	(9)	Intravenously....	2ccm					
(5 **Microgram per ccm Radium Solution**)..	(12)	Intravenously....	2ccm					
	(16)	Intravenously....	2ccm					

In the first column all the treatment factors are noted, both for the Roentgen and the radium treatments. In addition, the concentration of radium emanation in the treatment rooms, the quantity of radium solution given intravenously, etc., is noted. This brief notation of the constant factors saves much space.

Blank forms can be printed with the smybols MA, K.V., etc., on the card. In the illustration the entries which may be printed directly on the form have been given in heavy type; the values to be entered in ordinary type.

The second column gives the date of the treatment.

In the third column are noted the regions of application and size of field. In this, as well as in the next column, nothing can be printed in advance since the entries vary from case to case.

In the fourth column is entered the amount of energy applied to the separate areas; MA min., in the case of Roentgen rays; mghrs. in the case of radium; solutions are given in terms of cubic centimeters; inhalation of emanation in hours, etc.

The fifth column is reserved for the estimated or measured distribution of the applied energy. The dose given to the skin as well as to organs which are to be protected (bladder, rectum, spleen, etc.), in particular the dose administered to the area to be treated (tumor, glands, etc.) are entered here. A few designations can be printed on the form, but it is better to enter the organs involved from case to case. The Roentgen and radium energies are entered separately, and their sum is also noted. At the present stage of the technique it is best to state the energy in percentage of the skin dose, the latter being designated by 100%; the quantity can also be stated in physical units, in e or F units, but by this method the comparison of Roentgen and radium energies becomes more difficult.

In the last column the reaction of the organ treated and the reaction of the patient as a whole is noted.

The entire arrangement gives a comprehensive view of the chosen technique, the applied physical dose and the particular and general reactions produced; in this way it records that which is essential from the viewpoint of practical treatment and scientific experimentation.